Vegetation-soil relations in a highly sodic landscape, Yelarbon, southern Queensland

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Soil and vegetation data were collected from a sodic-scald near Yelarbon in southern Queensland. The surface of the landscape includes relatively light textured pedestals of the A-horizon with slightly alkaline pH and slopes leading down to scalded basement representing the surface of the strongly alkaline B-horizon. The strongest gradient within the floristic patterns was associated with wetland vegetation in drainage lines, but a secondary and orthogonal gradient was related to soil pH, which was probably a function of lower alkalinity on the more stable and weathered A-horizons. There were few significant differences between soil or vegetation characteristics from plot data comparing parts of the landscape with differing historical grazing regimes. Sites included stock routes heavily grazed between the 1920s and 1970s, and subsequently almost ungrazed; and grazed paddocks that have had moderate use throughout this period. There is clear evidence that the area is naturally active in terms of erosion and deposition during flooding regardless of grazing.

***Cunninghamia* 10(2):273–284**

Introduction

High sodicity and/or salinity are a prominent feature of inland Australian landscapes (Chartres 1993). While these characteristics are a function of natural processes, their significance increases when they lead to land degradation such as 'scalding', in which the surface horizons are removed, exposing chemically and/or physically hostile subsoils.

Scalds in eastern Australia generally develop from removal of surface soil (A horizon) and exposure of subsoil (B horizon) via wind- or water-driven sheet erosion. Scalds in southern inland Queensland are frequently associated with natural alluvial features often on the rarely flooded margins of floodplains (Land unit 66, Galloway *et al*. 1974; Land Unit 35, Dawson *et al*. 1974; Land unit 8, 13, Mills *et al*. 1990). Despite saline or sodic-scalds being relatively common in semi-arid Australia, there are few studies describing the vegetation associated with these areas (Kreeb *et al*. 1995), other than general land resource surveys. At Yelarbon in southern Queensland, there is a particularly prominent scald known locally as the 'desert' and this paper presents a detailed quadrat survey of both the scalded land and the surrounding area.

Sodicity and salinity are often confused because most saline soils in eastern Australia are also sodic, i.e. have a high proportion of sodium in relation to calcium, magnesium and potassium. The associated presence of high chloride and sulphate are the most common contributors to high salinity. Sodicity is generally a feature of subsoils rather than surface horizons, and sodic texture-contrast soils are widespread in eastern Australia (Rengasamy and Olsson 1991). Scalds with exposed sodic materials demonstrate crusting to hardsetting characteristics, with limited moisture infiltration (thus further propagating sheet erosion). Germination and re-colonisation by vegetation is limited by both physical and chemical factors (Ringroase-Voase et al. 1989; Qadir and Schubert 2002).

Despite a fairly detailed understanding of the physical and chemical processes within sodic soils that render them susceptible to degradation (Qadir and Schubert 2002), there are few systematic studies of the relationship between vegetation and sodic soils and the relative importance of intrinsic factors and grazing management. Vegetation patterns on sodic soils in Zimbabwe have been explained in relation to natural landscape processes as they determine soil condition without any consideration of land-use (Dye and Walker 1980). Kreeb *et al*. (1995) suggested that sodic-scalds in northern New South Wales are not primarily a product of land-use but result from deposition of sodic salts from groundwater and their accumulation as soils dry out in a seasonally arid climate.

The design of this survey in the Yelarbon sodic-scald capitalised on contrasting land-use either side of stock route fence-lines to assess the relative impact of natural processes and management on surface features, soil chemical conditions and vegetation patterns.

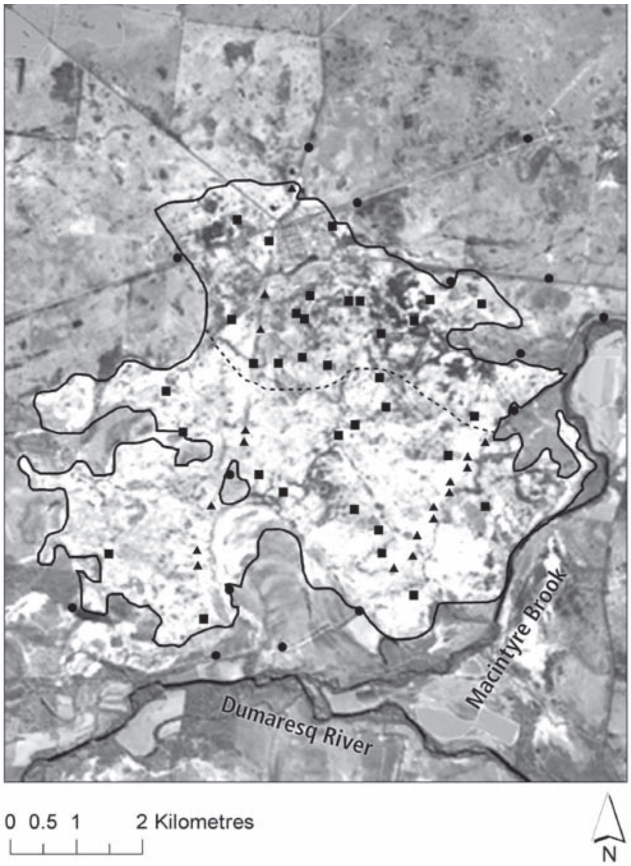

Fig. 1. The Yelarbon sodic-scald area as delineated by Queensland Herbarium mapping (regional ecosystem 11.5.14, Sattler and Williams 1999) on 2001 landsat imagery. The white scalded areas represent the exposed A_2 horizon. Outlying areas of scalded soils are evident to the west of the main area. Yelarbon township is evident in the northern part of the sodic-scald. Context plots are indicated as circles, paired stock route comparisons as triangles and other sodic-scald plots as squares. Sites classified as 'upper catchment' are north of the dashed line.

Study area and land use history

The barren nature of the sodic-scald at Yelarbon (Fig. 1) gave rise to it being referred to as the 'desert' (Isbell 1957; Thwaites and Macnish 1991). It is clearly visible on remotely-sensed imagery and is approximately 34.4 km^2, although there are outliers of similar scalded land types to the west of the main area, and inliers of less extreme land types within the broad envelope (Fig. 1). Despite its local name, the climate is only subhumid, receiving a mean annual rainfall of 595 mm, with only a slight seasonal bias to the summer months (65% between October and March). The nearby town of Goondiwindi has mean monthly minimum temperatures between 4.9˚C and 20.1˚C and mean monthly maximum temperatures between 18.1˚C and 33.4˚C. The area has low relief and lies to the north of the junction of Macintyre Brook and the Dumaresq River, the latter forming the Queensland-New South Wales state border.

The lower parts of the Yelarbon sodic-scald comprise recent ox-bows and related active features, while the higher parts are older, less active alluvial plains, with relict flowpaths still evident. Major flooding events since 1925 were in 1956 and 1976 (flood-gauge height greater than 10.8 m at 'Bengalla', 9 km downstream from the junction of Macintyre Brook and the Dumaresq River).

The intact soils are Grey to Brown Sodosols and typically have a clay loam, moderately acid to neutral A-horizon with a strongly alkaline, highly sodic, medium clay subsoil with ESP (exchangeable sodium percentage) values between 40 and 90% (Isbell 1957; Thwaites and Macnish, 1991; A. Biggs unpublished data). Chloride content is about 500 mg/kg and subsoil EC varies from 0.5 to 1.5 dS/m (1:5 soil:water extract). Surface pH ranges from 5.5–6.5 and subsoil pH varies from 8–11. Bleached A2 horizons are variably present. . Large amounts of both soft and hard carbonate materials are present in the subsoils and exposed in eroded areas. The high pH coupled with extreme ESP suggests sodium carbonate and sodium bicarbonate are the dominant salts in the soil. The soils have undergone extensive sheet erosion as indicated by bare ground and terraced topography resulting in the exposure of the B horizon (Fig. 2) and massive tunnel erosion in lower catchment areas (Fig. 3). Exposed sub-soils are crusting to hardsetting.

The accumulation of sodium has been attributed to upwards leakage of Great Artesian Basin (GAB) groundwaters along the Peel Fault offset by Knight *et al.* (1989) although Chen (2003) argued that the evolution of the area could have been driven by hydraulic heads associated with the Dumaresq River and Macintyre Brook. The combination of these pressure gradients downstream of two major streams provides a logical mechanism for upward vertical leakage. The confining beds of siltstone overlying the aquifer bearing Kumbarilla sandstones have been stripped away at Yelarbon, probably by a previous flow path of Macintyre Brook (Fig. 1), but are still intact to the east and west (Biggs *et al*. 2005). The contact between the sandstone basement and the overlying alluvium at Yelarbon is unclear, as the sandstones are often saturated and weak, thus resembling the sandy alluvia when drilled (Biggs *et al*. 2005). Extreme sodium levels (exchangeable sodium percentage ~90) and high proportions of both soft and hard carbonate segregations in the soils apparently reflects the Na–HCO_3-rich GAB groundwater in the area. Soils of the district do not normally evolve this chemistry, thus supporting the suggestion of a GAB contribution to the Yelarbon landscape. It is probable that the combination of transported salts from both streamflow and deeper GAB groundwater compound to produce the extreme environment of the Yelarbon desert.

The dominant tree on the sodic-scald is *Allocasuarina luehmanii* with *Melaleuca densispicata* common along drainage lines. Widely spaced hummocks of spinifex (*Triodia scariosa*) are also moderately abundant. There are ephemeral wetlands throughout the drainage lines of the scald and they were evident as free-water during the conditions of sampling after a wet summer.

Fig. 2. The pedestaled surface feature and scalded sub-soil basement in a typical landscape scene at the Yelarbon sodic-scald.

Fig. 3. Gully erosion in lower catchment areas at the Yelarbon sodic-scald.

The Yelarbon area was initially settled in the 1840s and would have been part of a large essentially unfenced pastoral holding from this time until closer settlement about the turn of the twentieth century. In addition to grazing by domestic stock the area would also have been subject to grazing pressure by rabbits, which were in sufficient numbers in the district to support a thriving rabbit works until the advent of myxamotosis in the 1950s (McLean 2002). Rabbits were never abundant on the sodic-scald because the thin top soils and unstable, hardsetting subsoils was unsuitable for warrens (J. Lennon pers. comm.), but the area would have experienced waves of rabbits migrating from adjacent densely populated areas to the east and south-west (D. Berman pers. comm.)

Two major stock routes approximately 50–100 m wide bisect the Yelarbon sodic-scald (Fig. 4). Land survey plans indicate that these stock routes were surveyed in 1898, and were fenced some time in the next 20 years (B. Wallace pers. comm.). The memory of long-term residents confirms very intensive grazing on the stock routes until trucking became the popular mode of transport from about the 1960s. The intensive use of the stock routes caused almost total removal of vegetative cover and scalding clearly evident on aerial photography (Fig. 4). Since this time the stock routes are only rarely used for grazing. The presence of the toxic plant *Bryophyllum delagoense* since the 1950s renders the stock route unsuitable for unaccustomed cattle. Thus the history of the stock route can be summarised as extensively denuded by stock, followed by a long period of grazing conditions conducive to recovery. All of the landholders were interviewed to describe their stocking rates and most of the area is relatively lightly stocked with the equivalent of 1 sheep to 1.7 ha or 1 heifer to 20 ha, with limited areas subject to even lighter stocking.

Methods

The following sites were selected:

Data from 36 plots (18 pairs) either side of the stock route–paddock fence-lines was collected to determine differences between sites with contrasting management histories. The paired sites were positioned within the sodic-scald land type at pre-determined regular locations along the stock routes where the vegetation was not wetland (free water at the time of sampling) and where there was no evidence of mechanical disturbance. The elongated plots were positioned parallel to the fence and were as close together as possible (typically 10 m).

34 extra plots were located within the grazed areas of the sodic-scald land type. These plots were positioned to represent the variation within the sodic-scald land type across its geographic range, including less common elements such as wetlands.

To provide a comparison to determine the extent to which the sodic-scald plots are distinct, 15 context plots in vegetation outside, but within 2 km of the sodic-scald were also sampled. Some of these context plots were within stock routes and others in grazed paddocks.

All vascular plants were recorded within a 50 m × 2 m quadrat and voucher specimens have been lodged at the Queensland Herbarium. Cover was recorded as the crown intercept along the central 50 m axis in the following categories: 0–1, 1–5, 5–10, 10–20, 20–30 m etc. and assigned as the mid-point of these categories. Sampling was conducted in March 2006 when conditions were ideal after a wet season of regular and substantial rainfall, although some winter annuals would have been poorly recorded. A brief plant survey in October 2006 records winter flowering annual species that may have evaded detection in the main survey. At ten regularly spaced points on the tape the following information was recorded:

- The depth of water;
- Soil penetration depth (an index of surface soil structure), measured by pushing an 8 mm blunt-ended steel rod with a horizontal cross-bar into the ground with upper body weight of a 90 kg person;
- Surface features as a) Pedestal (the upper horizontal land surface within the local area), b) Basement (scalded areas where the sub-soil basement is exposed after erosion), c) slope (erosion or deposition producing a graded surface between Terrace and Basement), or d) depression or drainage line;
- Ground cover type as a) vascular plant, b) cryptogam, c) litter or d) bare ground.

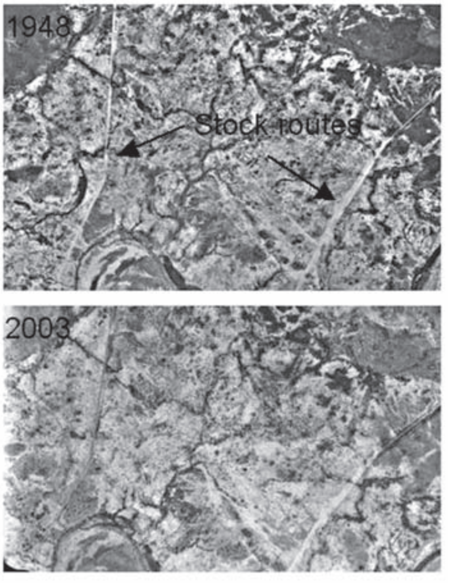

Fig. 4. Aerial photograph comparison of portion of the Yelarbon sodic-scald. The scalded nature of both the western and eastern stock route is clearly evident in the 1948 image. The scalded signature of the eastern stock route has persisted on the 2003 image.

A soil sample was taken from the highest point of each plot and assessed for pH using a TPS WP–81 pH meter (TPS Pty Ltd, Brisbane) with a 1:5 soil:water solution.

Nine plots spaced throughout the scalded area were selected to describe surface features of the non-wetland sodic-scald plots. At each of these sites a surface (1–5 cm depth) sample was taken and pH and soil texture according to the textural grades of McDonald *et al*. (1990) determined.

Data analysis

To describe the physical differences between the surface feature categories, box-plots were prepared of probe penetration depth for the sodic-scald sites only and comparisons made using the Kruskal-Wallis test where Z score differences greater than |2| indicated significant difference between means.

Plots were assigned to upper catchment and lower catchment after interpretation of elevation from 1:40 000 aerial photography using a stereoscope (Fig. 1). To determine the extent to which sodic-scald wetland plots (presence of free water) and non-wetland plots, and the context plots from the surrounding landscape are distinct from one another, their position in ordination space was examined. The site-species data were ordinated using non-metric multi-dimensional scaling using the default settings in DECODA (Minchin 1990) after adjusting cover scores to unit maxima. Exploratory analysis suggested that three dimensions accommodate the direction of all significant sample variables for the total dataset. A second analysis was conducted including the sodic-scald plots only and a two-dimensional solution was found to adequately represent the direction of sample variables. Vector analysis was used to examine the strength of correlation between the surface feature category cover scores (represented as separate proportions of the four categories), catchment elevation, pH and grazing index (0, stock route; 1, paddock), and floristic gradients represented by the ordination. The response of species in relation to environmental correlates was determined as average values in sites where the species are present after weighting using raw cover scores.

Stock route-paddock pairs were analysed separately using Wilcoxon's Test to compare count scores for the landscape and ground cover categories, mean soil penetration depth, the cover scores of nineteen species with a frequency greater than ten. A third ordination was conducted including only stock route-paddock pairs to investigate the potential role of grazing on floristic composition.

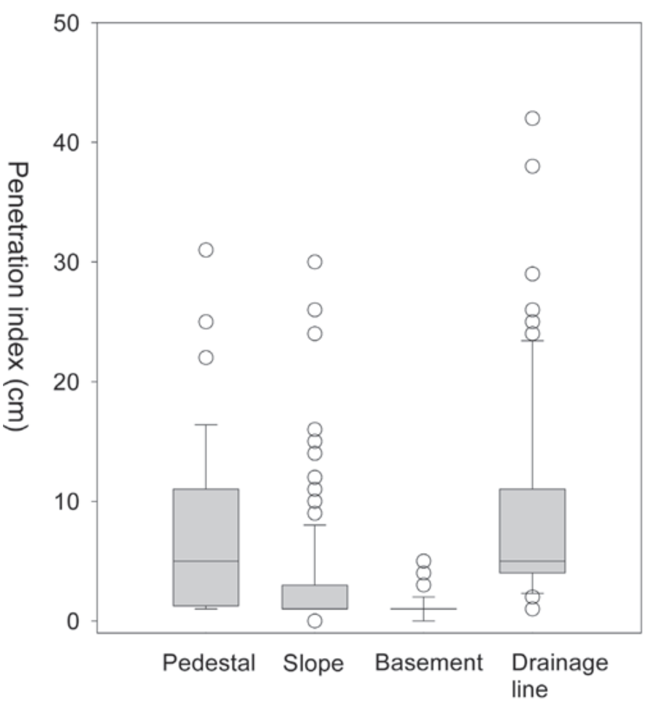

Fig.5. Box plots of the Soil penetration depth for the four microtopography categories. The median is identified within the box, limits of the box identify the 25th and 75th percentile, error bars identify the 10th and 90th percentiles, and circles are outliers. All pairs are significantly different based on Z value differences greater than |4| and an overall H value of 191.5 (P<0.001).

Results

Soil penetration depth was relatively high for the Pedestal surface feature, lower for Slope and almost zero for Basement—concomitant with the hardsetting surface found in the latter areas (Fig. 5). High median values for drainage lines indicate damp soils at the time of sampling.

Drainage areas have the highest vascular plant cover followed by pedestal, slope and basement. The latter has by far the greatest bare ground. Cryptogam cover is also low compared to slopes and basement (Table 1).

Soil-texture of the Pedestal was either light sandy clay loam or silty loam. The slopes were generally similar but could span a broader range from sandy loam to silty clay. The basement was always either light clay or medium clay. Soil pH graded from median values of 7.4 for the pedestal, 7.9 for the slope and 8.7 for the basement, with the highest value recorded being 9.6 (Fig. 6). The ordination of the 215 plant species in the 115 plots indicates a separation between the floristic composition of the sodic-scald plots and the surrounding landscape (Fig. 7), although the overlap indicates that some plots are related to non-scalded land types and that scalded land types occur outside the main area (Fig. 1). A high proportion of the total flora (71 species) was only recorded in the context plots. Despite the number of plots, only 64 species were only recorded from the sodic-scald area. Frequently recorded species that were faithful (absent from the context plots) to the sodic-scald plots include *Atriplex leptocarpa* (46 plots), *Portulaca australis* (17 plots), *Sarcozona praecox* (17 plots), *Triodia scariosa* (16 plots), *Plectranthus*

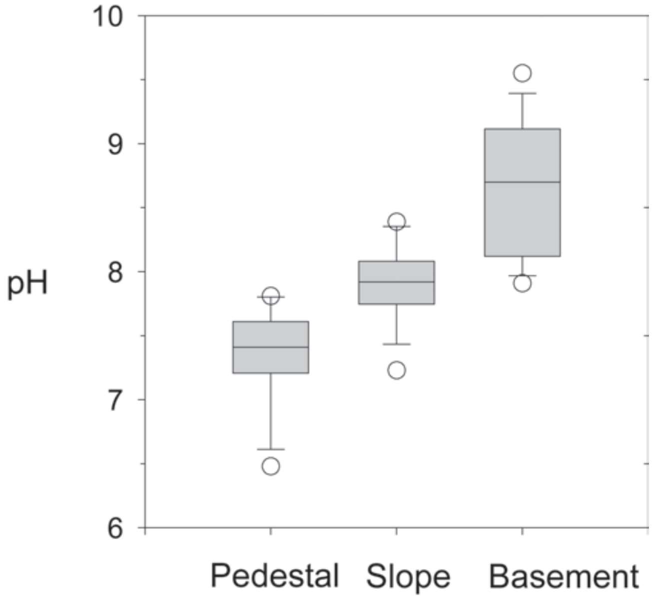

Fig. 6. Box plots of pH for three non-wetland microtopography categories. The median is identified within the box, limits of the box identify the 25th and 75th percentile, error bars identify the 10th and 90th percentiles, and circles are outliers. All pairs are significantly different based on Z value differences greater than |3.5| and an overall H value of 17.8 (P<0.001).

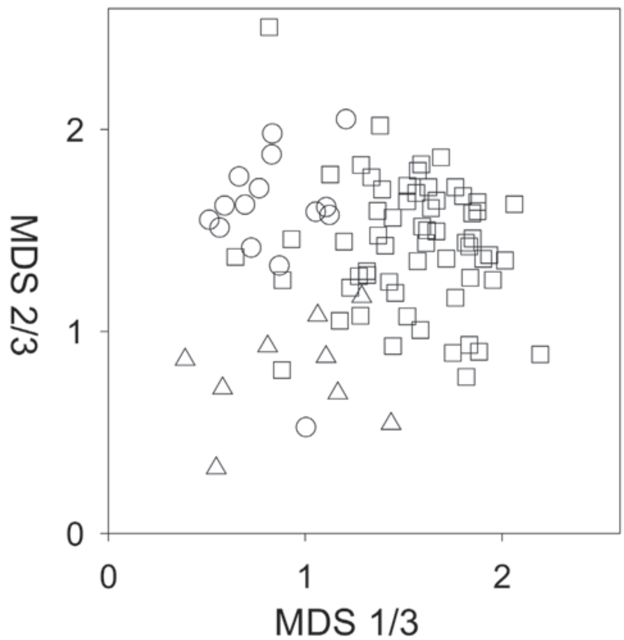

Fig. 7. First two axes of a three-dimensional ordination, including all sites. Squares represent the dryland sodic-scald sites, triangles the wetland sodic-scald sites, and circles the plots from other vegetation types in the surrounding landscape.

parviflorus (13 plots) and *Portulaca bicolor* (12 plots). Wetland plots within the sodic-scald are also floristically distinctive occupying a discrete portion of the ordination space. There were 18 species only recorded from the 10 plots that included some wetland within the sodic-scald area and the most frequent of these were *Leptochloa fusca* (9 plots), *Cyperus difformis* (6 plots), *Eleocharis pusilla* (5 plots), *Brachyscome basaltica* (4 plots) and *Goodenia gracilis* (4 plots).

Drainage line is also directly parallel and strongly related to the primary gradient within an ordination of the sodic-scald plots only. A secondary gradient almost orthogonal to the primary gradient is strongly related to pH (Fig. 8). The pH vector is roughly parallel with an increasing incidence of basement, and the direction of this vector is opposed to the vector relating to upper catchment sites.

The most frequent species in the 70 sodic-scald plots were *Tripogon loliiformis* (57 plots), *Sporobolus coromandelianus* (55 plots), *Fimbristylis dichotoma* (54 plots), *Sclerolaena tricuspis* (52 plots), *Portulaca oleracea* (49 plots) and *Atriplex leptocarpa* (46 plots). Together with other species they form short grassland on the Pedestal and Slope surface features. The scores of species along the two most significant vectors, drainage lines and pH were collated. The species with high drainage lines scores tend to be fairly rare representing the relative scarcity of wetland sites. *Fimbristylis dichotoma* has an association with low pH sites and *Sporobolus coromandelianus* and *Atriplex leptocarpa* with high pH sites (Appendix).

Table 1. Count intercepts (percentage cover) for the surface feature categories according to ground cover type for sites within the sodic-scald land type.

Landform	**Plant**	**Cryptogam**	**Litter**	**Bare**	**Grand Total**
Drainage line	56 (82.4)	2 (2.9)	1 (1.5)	9 (13.2)	68
Pedestal	26 (60.5)	9 (20.9)	0 (0.0)	8 (18.6)	43
Slope	143 (32.9)	149 (34.3)	24 (5.5)	119 (27.4)	435
Basement	9 (5.8)	14 (9.1)	0 (0.0)	131 (85.1)	154
Grand Total	**234 (33.9)**	**174 (25.2)**	**25 (2.8)**	**267 (38.1)**	**700**

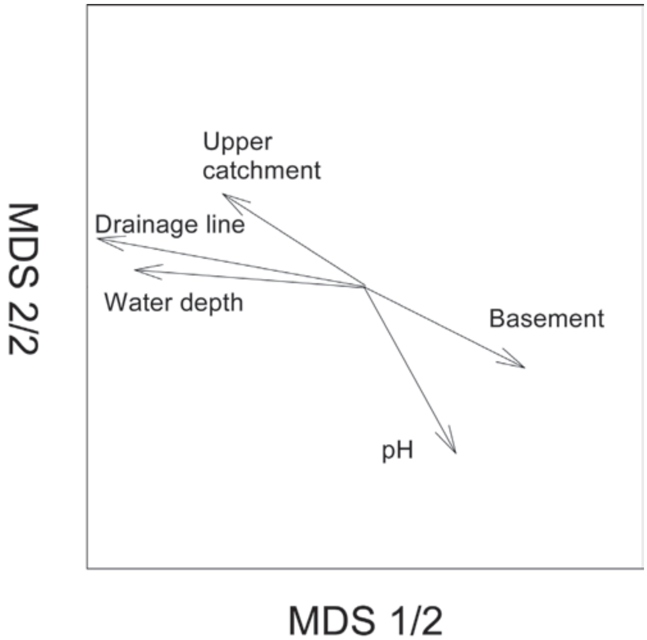

Fig. 8. Highly significant vectors (*P*<0.001) through the two-dimensional ordination solution for saline scald plots. Vectors for grazing index and cover of Slope and Pedestal microtopography categories are non-significant (*P*>0.05).

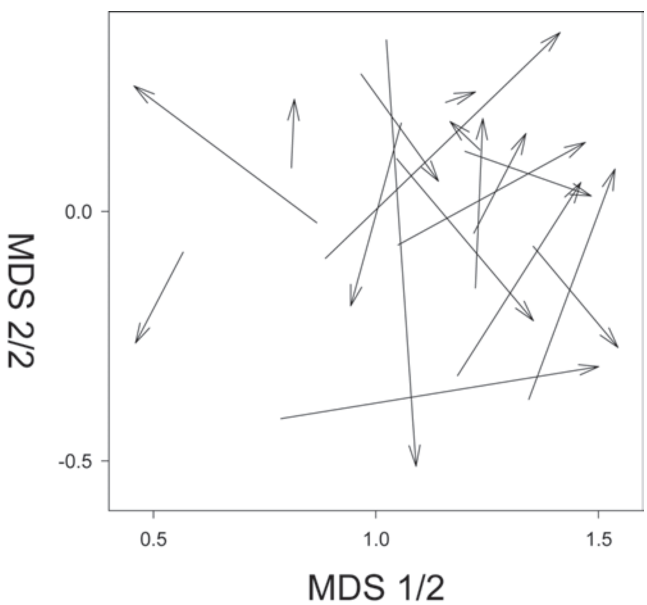

Fig. 9. Two-dimensional ordination of stock route-paddock paired plots. The arrows join stock route-paddock pairs with the tail on the position of the stock route and the head on the position of the paddock.

There were no significant differences (P>0.05) in frequency of surface feature categories between stock route and paddock. Plant cover was more frequent on the stock route than the paddocks (Median difference = 10%), although the significance was weak (Wilcoxon statistic = 26.5; N for test = 16; *P*-value = 0.034) and could be accounted for by multiple comparisons in the context of alpha error (Rice 1989). There was no significant difference between stock route and paddock for any other ground cover types, nor for soil penetration depth.

Of the 19 relatively frequent species in the stock route-paddock plot pairs, only *Portulaca pilosa* (Median difference in cover = 0.25%; Wilcoxon statistic = 5.5; N for test = 10; *P-value* = 0.028) and *Verbena aristigera* (Median difference in cover = 0.25%; Wilcoxon statistic = 0.0; N for test = 7; *P-value* = 0.022) were more abundant on the stock routes, although the weak significance of the results is inconclusive in the context of multiple comparisons. The small differences in floristics between ungrazed stock routes and paddocks are also demonstrated by their relative position within the ordination. Paddocks and stock routes for paired plots straddling fence-lines have no consistent relationship with ordination dimensions and may be neighbouring or widely separated (Fig. 9).

Discussion

The soils at the Yelarbon sodic-scald are extreme and the vegetation is clearly distinct from the surrounding landscape. *Brachyscome* sp. (RJ Fensham 5553) may be endemic to the sodic-scald and another suite of faithful species (*Angianthus brachypappus*, *Disphyma crassifolium, Lepidium monoplocoides, Maireana pentagona* and *Sarcozona praecox*) are at their northern limit at Yelarbon. The disproportionate number of succulent species in the sodic-scald area suggests that succulence is an adaptation to the extreme conditions, with the succulent family Aizoacae well represented (Appendix). The most abundant of the indicator species for the sodic-scald were *Atriplex leptocarpa* and *Sporobolus coramandelianus*. These species are reasonably widespread and may represent useful indicators of high sodicity or salinity in other areas. Some species such as *Tripogon loliiformis, Fimbristylis dichotoma, Sclerolaena tricuspsis* and *Portulaca oleracea* are common on the sodic-scald and widespread in other environments.

There is some similarity between the vegetation descriptions from land resource assessment studies from areas in southern Queensland to the west of Yelarbon (Land unit 66, Galloway *et al*. 1974; Land Unit 35, Dawson *et al*. 1974; Land unit 8, 13, Mills *et al*. 1990). In the brief descriptions provided in these reports, the grasses *Dactylotenium radulans* and *Tripogon loliiformis,* and *Trianthema triquetra* are typical and are also common at Yelarbon (Appendix). The chenopod genera *Atriplex* and *Sclerolaena* are also a common feature of scalds, but not necessarily the same species that are common at Yelarbon. Reports from other areas to the south in New

Fig. 10. Aboriginal hearth places have been exposed by erosion at Yelarbon and may yield important evidence relating to the landscape history and dynamism of the sodic-scald at Yelarbon.

South Wales come from locations that have been heavily altered by land clearing and pasture development, and are generally more temperate (i.e. Kreeb *et al*. 1995; Briggs and Taws 2003).

Drainage depressions forming ephemeral wetlands are a strong determinant of vegetation pattern, but the indicator species (Appendix) are generally widespread and also occur in wetlands of non-sodic landscapes.

Within the sodic-scald area, a primary floristic gradient is correlated with the pH of the surface soil (Appendix). This floristic gradient is represented at the high alkalinity end by species capable of growing on the extreme environment of the scalded sub-soils, and at the low alkalinity end by species associated with the leached residual A-horizons that have persisted in upper catchment areas. The most frequent of the non-wetland species at the high alkaline end of the pH vector are *Atriplex leptocarpa, Portulaca pilosa, Sporobolus coramandelianus* and *Trianthema triquetra*; with *Bryophyllum delagoense, Chloris ventricosa, Dactyloctenium radulans, Enteropogon acicularis, Fimbristylis dichotoma, Salsola kali* most frequent at the less alkaline end of this vector.

The sodic-scald at Yelarbon spans multiple levels of alluvia at the junction of two substantial streams, the Dumaresq River and MacIntyre Brook (Fig. 1). Lower areas are flooded from over-bank flow, while the highest areas experience overland flooding. Run-off during extreme flood events probably accounts for the majority of soil loss at Yelarbon, as is the case for other areas of western New South Wales (Fanning 1999). Local knowledge verifies that mass soil movement is mostly confined to extreme rainfall events that result in the flooding of the Dumaresq River or Macintyre Brook as occurred in 1956 and 1976. Run-off velocity and volume is highest in the lower reaches where major soil loss is evident as deep erosion gullies (Fig. 3). The study of McIvor *et al*. (1995) suggests that plant cover below 40% did not exacerbate soil movement during extreme events, while Eldridge and Rothon (1992) attributed weak relationships between soil movement and plant cover to the high porosity of the soil at their study site in New South Wales. It seems likely that surface soils at Yelarbon are highly vulnerable to sheet erosion given their dispersive character, the hard-pan formed by the sub-soil, a climate that can oscillate between drought and flooding rain in a short period, and the inherently unfavourable environment for plant growth.

Deposition also occurs in some areas during flood events. Aboriginal hearth-places have been buried by flood deposits and subsequently exposed by erosion (Fig. 10). Flood deposits support sparse vegetation dominated by perennial short grassland dominated by *Sporobolus coramandelianus, Tripogon loliiformis, Fimbristylis dichotoma, Sclerolaena tripcuspis* and *Atriplex leptocarpa* short-grassland akin to that on the sodic-scald at large. Many areas of the Pedestal surface features may be remnants of old flood deposits.

Fig. 11. Stripping of the A-horizon along the stock route (right)-paddock (left) fence at the Yelarbon sodic-scald. This is evident as the scalding on the eastern stock route on Fig. 4.

Surface soils of the Pedestal may also be formed by lateral drainage of water removing dispersed clays out of surface material. This means of profile development has been postulated for sodic soil-catenas in Africa (Dye and Walker 1980). Further study of the landscape processes that formed and maintain the extreme environment of the sodic-scald could provide important insights relevant to the management of the large areas of semi-arid Australia soils affected by primary and secondary (management-induced) scalding by sodicity and salinity. The aboriginal hearths contain charcoal, which could be dated to give some temporal perspective on landscape processes (Holdaway *et al*. 2002).

There was no obvious change in the pattern of scalded area between 1948 and 2003 (Fig. 4). A grazing effect on vegetation pattern, soil cover or surface feature patterns was not clear from the plot data although a residual signature of the historical grazing impact on the stock route remains evident on the recent aerial photography and in some places in the field (Fig. 11). Grazing gradients constructed across fence-lines have been demonstrated to have substantial effects on soil surface conditions including cryptogamic crust cover, plant litter, pH and infiltration (Graetz and Tongway 1986) and vegetation composition in other Australian environments (Fensham *et al*. 1999). It is possible that grazing use had a substantial impact prior to the establishment of the stock route fence in the early part of the twentieth century. In the early decades of settlement free ranging stock and plagues of rabbits may have denuded vegetation sufficiently to have accelerated erosion. However, the Yelarbon sodic-scald is a naturally active landscape regardless of grazing.

Acknowledgements

We thank the Queensland Murray Darling Basin Commission for their support of this project, and especially Alison Goodland for organising the project. We also thank Ian Menkins for assistance with fieldwork and plant identification and Nick Cuff for preparing Figure 1. Michael Strong is thanked for advice confirming the identity of the aboriginal hearth places and Kristie Watling provided information on soils. Discussions with long-term residents including Jeff Girle, Beryl Wallace and John Lennon provided invaluable insights.

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Manuscript accepted 21 August 2007

Appendix 1

Vascular plant pecies list for the Yelarbon sodic-scald species only, and the frequency of their occurrence in the 70 plots. Nomenclature follows Bostock and Holland (2007). Species without frequency values were only found during the post-winter survey in October 2006. Exotic species are identified with an asterisk and succulent species with a hatch. Average scores (weighted by species cover) for the two most significant environmental correlates (see Fig. 8), pH and the Drainage line vectors are also provided. Drainage line scores represent the percentage of the transect that intersects with the drainage line microtopographic category. The vector scores are derived from the ordinal position of that species on the vector and relate directly to the range of scores for that variable. Thus the higher the score for pH the stronger the association with alkaline sites, and the higher the drainage vector score the stronger the association with sites with a high proportion of drainage surface feature (a surrogate for wetland habitat).

	Frequency	pH vector score	Drainage line vector score
PTERIDIOPHYTA			
Marsileaceae			
Marsilea hirsuta	9	7.48	6.94
Ophioglossaceae			
Ophioglossum lusitanicum	1	8.06	0
Sinopteridaceae			
Cheilanthes distans	18	7.98	0.83
Cheilanthes sieberi	7	7.63	2.29
ANGIOSPERMAE			
Acanthaceae			
Brunoniella australis	2	6.55	0.5
Rostellularia adscendens	2	7.49	0

Aizoaceae			
Calandrinia calyptrata#	2	7.86	0
Calandrinia pickeringi#	1	6.89	0
Calandrinia pumila#	1	7.43	0
Disphyma crassifolium#	1	8.44	0
Grahamia australiana#	5	7.24	1.67
Portulaca australis#	17	7.82	0.24
Portulaca bicolor#	12	7.59	0
Portulaca filifolia#	9	7.51	0.33
Portulaca oleracea#	49	7.76	0.25
Portulaca pilosa#	27	8.03	0.15
Sarcozona praecox#	17	7.94	0
Trianthema triquetra#	27	8.6	0.06
Amaranthaceae			
Alternantha angustifolius	6	8.09	4
Alternantha denticulata	8	7.47	4.75
*Gomphrena colesoides**	3	7.6	5
Nyssanthes erecta	1	7.5	10
Apiaceae			
Eryngium plantagineum	1	7.35	9
Asclepiadaceae			
*Gomphocarpus physocarpus**	1	8.1	0
Asteraceae			
Angianthus brachypappus	3	8.01	0
*Aster subulata**	3	8.6	1.33
Brachyscome basaltica	5	9.31	2.94
Brachyscome ciliaris	19	7.83	0.21
Brachyscome sp. (RJ Fensham 5553)	1	8.1	0
*Calendula arvensis**			
Calotis cuneifolia	2	7.43	0.5
Calotis hispidula			
Centipeda minima	2	7.6	3
Chrysocephalum apiculatum	1	8.1	0
*Conyza bonariensis**	2	7.49	0
Eclipta platyglossa	3	7.25	6.67
Epaltes australis	6	7.47	1.5
*Hypochaeris microcephala**	1	7.1	6
Lagenifera gracilis	2	7.19	5
Podolepis muelleri			
Soliva sessilis			
Triptilodiscus pygmaeus			
Vittadinia pustulata	21	7.92	0.62
Vittadinia sulcata	2	7.8	0
Boraginaceae			
*Heliotropium amplexicale**	5	7.59	2.2
Brassicaceae			
*Lepidium africanum**	8	7.67	1.25
Lepidium monoplocoides	6	7.85	0.33
Cactaceae			
Harrisia martini#	2	7.35	0
Optunia aurantia#*	14	7.54	0.21
Opuntia stricta#*	14	8.12	1.36
Opuntia tomentosa#*	3	7.51	3.33
Campanulaceae			
Wahlenbergia fluminalis	12	8.06	0.58
Wahlenbergia gracilis	3	7.63	5
Casuarinaceae			
Allocasuarina luehmannii	9	6.49	0.01
Chenopodiaceae			
Atriplex leptocarpa	46	8.08	0.09
Atriplex semibaccata	17	8.01	7.58
Chenopodium carinatum	1	7.3	0
Einadia nutans	5	7.07	0.2
Einadia polygonoides	2	7.24	0
Enchylaena tomentosa#	14	7.45	0.67
Maireana microphylla	1	6.89	0
Maireana pentagona	8	7.25	1.75
Rhagodia spinescens	6	7.1	2.5
Salsola kali	28	7.45	0.15
Sclerolaena bicornis	15	7.61	0
Sclerolaena birchii	5	7.35	2.2
Sclerolaena muricata	3	7.37	3
Sclerolaena tricuspis#	52	7.51	0.19
Tetragona tetragonioides#	1	7.5	10
Clusiaceae			
Hypericum gramineum	1	8.1	0
Commelineaceae			
Commelina cyanea	19	7.78	1.42
Murdannia graminea	4	8.43	9.76
Convolvulaceae			
Dichondra repens	1	7.5	10
Evolvulus elsinoides	3	6.92	0
Crassulaceae			
Bryophyllum delagoense#*	33	7.22	3.09
Crassula sieberiana			
Cupressaceae			
Callitris glaucophylla	1	8	0
Cyperaceae			
Bulbostylis barbata	3	7.43	0
Carex appressa	2	7.35	8.97
Carex inversa	3	7.3	7
Cyperus difformis	7	7.4	5.67
Cyperus gracilis	3	6.72	0
Cyperus rigidellus	6	6.93	8.2
Eleocharis blakeana	1	6.8	9
Eleocharis plana	4	8.03	0.47
Eleocharis pusilla	5	8.37	9.62
Fimbristylis dichotoma	54	7.45	3.59
Euphorbiaceae			
Chamaesyce drummondii	8	7.43	2.5
Phyllanthus virgatus	3	7.66	0
Fabaceae			
Glycine clandestina	3	7.5	3.33
Medicago minima			
Goodeniaceae			
Goodenia gracilis	4	7.73	6.5
Haloragaceae			
Haloragis heterophylla	1	8.1	0
Myriophyllum gracile	1	7.2	3
Hypoxidaceae			
Hypoxis hygrometrica	1	8.1	0
Juncaceae			
Juncus subsecundus	5	7.35	8.5
Lamiaceae			
Plectranthus parviflorus#	13	7.53	2
Liliaceae			
Bulbine semialata	3	8.04	0
Crinum flaccidum	1	7.1	6
Malvaceae			
Abutilon oxycarpum	4	7.08	2.75

*Sida rhombifolia**	1	10	2
Sida trichopoda	7	7.2	3.33
Menyanthaceae			
Nymphoides crenata	2	7.28	5.13
Myoporaceae			
Eremophila deserti	3	7.74	0
Eremophila longifolia	1	8	0
Eremophila debile	3	7.2	3.33
Myrtaceae			
Melaleuca densispicata	9	7.28	4.26
Nyctaginaceae			
Boerhavia repleta	6	7.12	1.67
Oleaceae			
Notelaea microcarpa	2	7	5
Oxalidaceae			
Oxalis chnoodes	4	7.45	3.75
Oxalis perennans	2	7.45	3.75
Phormiaceae			
Dianella longifolia	2	8.11	0
Pittosporaceae			
Pittosporum angustifolium	1	6.8	3
Plantaginaceae			
Plantago turrifera			
Poaceae			
Aristida jerichoensis	2	6.85	0
Aristida leichhardtiana	1	6.35	0
Aristida longicollis	2	7.5	5
Aristida ramosa	2	8.89	0.5
Austrodanthonia linkii	2	6.93	5
Austrostipa scabra	4	7.45	2.5
Bothriochloa decipiens	13	7.76	2.14
*Cenchrus ciliaris**	2	7.4	5
Chloris divaricata	1	8.1	0
*Chloris gayana**	1	8.3	0
Chloris truncata	17	7.87	1.61
Chloris ventricosa	18	7.49	3.49
Cymbopogon refractus	7	7.51	2.14
*Cynodon dactylon**	6	8.28	0.24
Dactyloctenium radulans	21	6.93	8.2
Dichanthium sericeum	3	7.8	3.67
Digitaria brownii	2	7.7	0
Digitaria diffusa	3	7.5	3.33
Digitaria divaricatissima	2	7.78	5
*Echinochloa colona**	1	7.1	6
Enneapogon gracilis	12	7.89	0.48
Enteropogon acicularis	19	7.25	0.23
Eragrostis alveiformis	6	7.95	0.17
*Eragrostis curvula**	1	8.44	0
Eragrostis elongata	3	8.47	1.67
Eragrostis lacunaria	9	7.21	0.1
Eragrostis leptostachya	4	7.21	2.5
Eragrostis parviflora	15	7.86	3.76
Eragrostis sororia	9	7.58	1.13
Eriochloa pseudoacrotricha	23	7.5	7.18
Eulalia aurea	1	7.3	5
Leptochloa decipens	6	6.99	0.65
Leptochloa digitata	1	7.3	5
Leptochloa divaricatissima	1	6.35	0
Leptochloa fusca	10	7.58	7.71
Oxychloris scariosa	2	7.86	0
Panicum buncei	11	7.95	2.18
Panicum effusum	1	8.1	0
Paspalidium caespitosum	3	7.11	0
Paspalidium constrictum	4	7.36	0.25
Paspalidium distans	5	7.32	1.6
Paspalidum gracile	1	8	0
*Paspalum dilatatum**	2	7.52	3.67
Paspalum distichum	2	7.35	9.03
Poa fordeana			
*Melinis repens**	1	7.32	0
Setaria parviflora	1	10	2
Sporobolus caroli	1	8.33	2
Sporobolus coramandelianus	55	8.04	0.21
Sporobolus creber	3	7.15	0
Tragus australiensis	29	7.94	0.41
Triodia scariosa	16	7.8	0.16
Tripogon lolliformis	57	7.6	0.19
Vulpia muralis			
Walwhalleya subxerophila	1	7.1	6
Rubiaceae			
Oldenlandia trachymenoides	1	8.1	0
Psydrax oleifolia	2	7.8	5
Rutaceae			
Geijera parviflora	3	7.5	3.33
Santalaceae			
Santalum lanceolatum	3	7.87	3.33
Scrophulariaceae			
Glossostigma diandrum	2	7.35	7
Peplidium foecundum	1	8.5	10
Solanaceae			
Solanum ferrocissimum	2	6.99	3.33
Thymeleaceae			
Pimelea neo-anglica	2	6.8	3
Verbenaceae			
*Verbena aristigera**	22	7.95	0.64
Xanthorrhoeaceae			
Lomandra multiflora	1	8.1	0
Zygophyllaceae			
Tribulus terrestris	2	7.97	5