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Floristic composition and pasture condition of *Aristida/Bothriochloa* pastures in central Queensland. II. Soil and pasture condition interactions

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Abstract. Sustainable management of native pastures requires an understanding of what the bounds of pasture composition, cover and soil surface condition are for healthy pastoral landscapes to persist. A survey of 107 *Aristida/Bothriochloa* pasture sites in inland central Queensland was conducted. The sites were chosen for their current diversity of tree cover, apparent pasture condition and soil type to assist in setting more objective bounds on condition 'states' in such pastures. Assessors' estimates of pasture condition were strongly correlated with herbage mass ($r = 0.57$) and projected ground cover ($r = 0.58$), and moderately correlated with pasture crown cover ($r = 0.35$) and tree basal area ($r = 0.32$). Pasture condition was not correlated with pasture plant density or the frequency of simple guilds of pasture species. The soil type of *Aristida/Bothriochloa* pasture communities was generally hard-setting, low in cryptogam cover but moderately covered with litter and projected ground cover (30–50%). There was no correlation between projected ground cover of pasture and estimated ground-level cover of plant crowns. Tree basal area was correlated with broad categories of soil type, probably because greater tree clearing has occurred on the more fertile, heavy-textured clay soils. Of the main perennial grasses, some showed strong soil preferences, for example *Tripogon loliiformis* for hard-setting soils and *Dichanthium sericeum* for clays. Common species, such as *Chrysopogon fallax* and *Heteropogon contortus*, had no strong soil preference. Wiregrasses (*Aristida* spp.) tended to be uncommon at both ends of the estimated pasture condition scale whereas *H. contortus* was far more common in pastures in good condition. Sedges (Cyperaceae) were common on all soil types and for all pasture condition ratings. Plants identified as increaser species were *Tragus australianus*, daisies (Asteraceae) and potentially toxic herbaceous legumes such as *Indigofera* spp. and *Crotalaria* spp. Pasture condition could not be reliably predicted based on the abundance of a single species or taxon but there may be scope for using integrated data for four to five ecologically contrasting plants such as *Themeda triandra* with daisies, *T. loliiformis* and flannel weeds (Malvaceae).

Additional keywords: ground cover, indicator species, range condition, *Tragus australianus*, *Tripogon loliiformis*.

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Introduction

Sustainable management of natural resources relies upon having knowledge of the condition of the resource and many of its components, such as trees, soil, vegetation, water resources and wildlife. The *Aristida/Bothriochloa* pastures of the woodlands of central Queensland have been identified as a resource in need of appropriate long-term management for sustainable, diverse outcomes (Tothill and Gillies 1992; Walker 1997). Scanlan and McIvor (1993), McIvor *et al*. (1995) and Scanlan *et al*. (1996) found that adequate pasture cover in the north of the region was crucial for minimising runoff and soil erosion and that the adequacy of cover was significantly influenced by grazing management and pasture composition. They developed predictive equations that related runoff and soil loss to pasture cover, soil type and meteorological conditions. Recently, Scanlan *et al*. (2014) have linked pasture condition and erosion rates to the percentage of perennial grasses in tropical native pastures using the GRASP model. In silver-leaved ironbark (*Eucalyptus melanophloia*) woodlands with hard-setting surface soils in central Queensland, Silburn *et al*. (1992) found that a ground cover of 40–50% and above could greatly reduce soil loss from pastures in a range of condition. However, that research provided limited background information on the botanical composition of the pastures that accompanies the relationships.

The work we report here was from a detailed survey in the mid-1990s of many central Queensland *Aristida/Bothriochloa* pastures that relate pasture condition to the interaction of pasture structure, species abundance and the nature of the soil surface. The choice of sites, the detailed information on floristic composition and taxon groupings referred to in this paper are described in Silcock *et al*. (2015). The three broad tree overstorey sub-categories reported in Silcock *et al*. (2015; tables 4 and 8) – narrow-leaved ironbark (*Eucalyptus crebra*), silver-leaved ironbark (*E. melanophloia*) and poplar box (*E. populnea*), are used in this paper.

Methods

This research is based on the 107 naturally timbered sites in central sub-coastal Queensland described in Silcock *et al*. (1996, 2015). Sites were chosen to represent a range of *Aristida/Bothriochloa* woodlands with varying prior management history in the headwaters of the Burdekin, Fitzroy, Condamine and Maranoa Rivers of central Queensland. They were mid-slope in a comparatively even tree density and ~100 × 300 m in size. Each site was subjectively rated for pasture condition between A+ (excellent) and C– (very bad) based on the concepts described by Tothill and Gillies (1992). A good condition pasture is dominated by palatable, productive, perennial grasses (3P grasses), has plenty of soil surface litter and a high proportion of the ground overtopped by the pasture while showing negligible signs of soil erosion. Overstorey tree density will reduce the pasture abundance but should have inconsequential effects on pasture condition but an excessive understorey shrub layer reduces the condition rating. A very poor condition pasture would have very few 3P grasses, have low ground cover of perennial pasture species, may contain undesirable weeds and will show clear evidence of serious soil erosion such as a scalded surface, gullies and abundant surface stones.

Standing pasture mass at the site was visually estimated as dry matter (DM) by experienced surveyors. A visual description was recorded at each site of two well separated soil cores dug deep into the B horizon with a 5-cm-diameter auger to assist in the classification of the soil into broad groups.

At each site, 50 evenly spaced quadrats (50 × 50 cm) were assessed for a range of pasture and surface soil features that contribute to pasture and landscape condition, and to the character of the pasture. The surface soil features were based on many of the landscape functional analysis attributes used by Tongway and Hindley (1995), namely ground cover percentage (including stones), litter and wash material type, erosion features, cryptogam cover and surface hardness. There was some subjectivity in rating these surface features, but the recorders were experienced rangeland scientists with QGraze monitoring training (QGraze 1994).

The pasture data collected in each quadrat were the five main species, the proportion of the live crown cover at ground level that each contributed, the number of plants of each main species, the estimated total living pasture crown cover percentage, projected ground cover rating (0–6) and the relative mass of standing pasture DM in each quadrat (0–5) in relation to the small-scale site standing pasture mass at the time. Silcock *et al*. (2015) provide more details of the pasture assessment methods. These pasture data were then processed to give overall site values for species frequency (%), pasture crown cover (%) and mean plant density m^{-2}, plus mean ratings for standing pasture DM and projected ground cover of standing pasture plus litter.

Table 1. Maximum, minimum and mean values or derived ratings for the pasture and soil variables for 107 sites

Variable	Units	Minimum	Mean	Maximum
Plant density[A]	Plants m^{-2}	13.9	47.8	96.4
Projected ground cover	Rating (1–6)	1.86	4.06	5.52
Crown cover	% estimate	0.15	1.57	6.47
Soil surface nature	Rating (0–4)	1.20	3.08	4.00
Cryptogam cover	Rating (0–2)	0.00	0.43	1.74
Soil surface accumulation	Rating (2–8)	3.46	6.17	7.92
Erosion severity	Rating (0–4)	0.00	0.59	2.26

[A]This is the density calculated from the five major species in each of the 50 quadrats assessed at a site.

Soil surface condition measures

The recorded soil surface data were transformed into quantitative ratings for numeric analysis and correlated with pasture variables on an individual quadrat basis. Correlations for overstorey tree type, tree basal area and pasture condition were done on a site-mean basis. The values given are a logical numeric progression related to the desirability of each parameter in that state but the relationship is not necessarily linear. The coded data for cryptogram cover had three categories (0%, <25% and >25%) with values of 0, 1 and 2, respectively; soil surface state had five categories (self-mulching, loose, weak coherence, moderate coherence and very strong coherence) with values of 0, 1, 2, 3 and

Table 2. Correlations among the assessed soil and pasture variables for all sites
Strong correlations are in bold font

	Plant density	Standing pasture DM	Projected ground cover	Living crown cover	Soil surface type	Cryptogam cover	Surface accumulations	Soil erosion type
Plant density	1.00		–	–	–	–	–	–
Standing pasture DM	0.040	1.00	–	–	–	–	–	–
Projected ground cover	0.140	**0.540**	1.00	–	–	–	–	–
Living crown cover	0.193	**0.564**	0.143	1.00	–	–	–	–
Soil surface type	0.242	–0.065	–0.058	0.037	1.00	–	–	–
Cryptogam cover	0.281	–0.045	0.086	–0.055	**0.602**	1.00	–	–
Surface accumulations	0.126	0.141	**0.434**	0.034	–0.108	–0.125	1.00	–
Soil erosion type	0.026	–0.370	–0.214	–0.247	0.287	0.083	–0.062	1.00

4, respectively; dominant visible erosion feature had five categories (nil, sheeting, pedestalling, scarps and rills) with values of 0, 1, 2, 3 and 4, respectively; main transported surface accumulation type had nine categories (rock, gravel, silt, sand, nil, dung, tree litter, general litter and pasture litter) with values of 2, 3, 4, 4, 5, 6, 7, 7 and 8, respectively; and nine categories of pasture condition (A+, A, A–, B+, B, B–, C+, C and C–) had values of 1, 2, 3, 4, 5, 6, 7, 8 and 9, respectively.

Soil types

Soil type was categorised on the evidence from the soil cores into Northcote's Principal Profile Forms (Northcote 1971) based on surface nature, sub-soil colour and texture changes with depth. They were placed into seven high level groups based on Northcote's Principal Profile Forms, namely:

Uc – uniform profile texture, coarse sandy matrix (often deep);
Um – uniform profile texture, medium texture matrix (often shallow, skeletal);
Gn – earths that gradually become more clayey at depth;
Dy – duplex soils, loamy surface over yellowish clay sub-soil;
Dr – duplex soils, loamy surface over reddish clay sub-soil;
Db – duplex soils, loamy surface over brownish clay sub-soil; and
Uf – heavy clay soils (may include cracking types).

Duplex soils have a sharp change in clay content between the surface layer and the sub-soil. Each site was also assigned to an Atlas of Australian Soils soil series (Isbell *et al*. 1967) based on its location and soil type.

Data analyses

The dataset was subjected to a range of GENSTAT statistical analyses (GENSTAT 2013) and tabulated sorting to find any discriminating factors and for correlations among variables. Means, medians and skewedness were calculated for each numeric site variable and were compared against classifications dealing with condition or soil type. Estimated pasture condition data were subjected to multivariate analysis using step-forward and all-subsets procedures to test multiple factors for useful relationships with key site variables. Some 300 herbaceous taxa were recorded but, for data presentation and final correlation analysis, they were consolidated into 58 groups or guilds (see Silcock *et al*. 2015; Table 7 and Appendix 1). These could be individual species of importance, genera, families or like plants within a taxonomic category. For example, *Aristida* spp. (wiregrasses) were split into four groups but Chenopodiaceae remained as a single diverse guild.

We also compared results within the three main overstorey tree groups defined in Silcock *et al*. (2015; Table 1), to present and interpret the data in a less general way. The pasture floristic composition of these three communities was not sufficiently different to allow mathematical differentiation of them by pattern analysis (Belbin 1987) as reported in Silcock *et al*. (1996). These tree communities, however, are readily recognised by landholders and scientists (FutureBeef 2014). The narrow-leaved ironbark group, as presented, includes a few sites from related hilly regions where cypress pine (*Callitris glaucophylla*), lemon-scented gum (*Corymbia citriodora*) or apple gums (*Angophora* spp.) were dominant over the narrow-leaved ironbark. Taxonomic nomenclature follows that of Henderson (1997) and members of the species groups are listed in Appendix 1 of Silcock *et al*. (2015).

Results and discussion

Individual sites

The data for each site were summarised for all pasture and soil variables and depicted in graphical format as illustrated in Silcock *et al*. (1996). Poor condition sites, such as the Rubyvale town common, which was highly disturbed, overgrazed and in B– condition by our 9-category system, had only 0.7% of total pasture crown cover whereas paddocks in good A condition had over 3.0% of crown cover, mostly of strongly perennial C_4 grasses. The B– condition at Rubyvale was also evident by the large proportion of crown cover due to annual grasses (20%) compared with a mean of 6.2% over all sites (Silcock *et al*. 2015; Table 2). Poor condition sites, such as Rubyvale Common, often have no cryptogam cover, limited litter (only 30% of quadrats with litter as the main surface accumulation feature) and a mix of moderate to very strongly coherent surface soil nature (86% of quadrats).

Summative data

The low mean plant crown cover at our sites (1.57%) reflects the recent poor seasonal weather conditions but the mean total ground cover rating of 4.1 out of 6 shows that cover was mostly adequate (Table 1). A rating of 4 on the QGraze scale (QGraze 1994) means an average of over 40% ground cover, which Silburn *et al*. (1992) consider the minimum required to limit serious soil erosion in the region. Pressland *et al*. (1988) consider that crown cover of native pastures in satisfactory condition should be at least 3%, which many in this study had, but some deliberately chosen for poor condition brought the average down – 11 sites had $\leq$0.5%. The soils at most sites were generally hard-surfaced with low cryptogam cover but not severely eroded (data not shown; see Silcock *et al*. 1996; table 3.1.1). Tree basal area at sites ranged from zero to 19 m^2 ha^{-1} with a mean of 3.4 m^2 ha^{-1}. Ten sites were quite densely timbered at over 10 m^2 ha^{-1}.

Broad correlations

There were strong correlations on an individual quadrat basis between some of the eight main site variables recorded (Table 2). An abundance of cryptogams on the soil surface was correlated with hard-setting soil surfaces (r = 0.60). There was a negative relationship (r = –0.37) between standing pasture DM rating and extent of erosion in an individual quadrat. This result was aided by a high negative correlation (r = –0.65) at silver-leaved ironbark sites. The correlation was lower when the site

Table 3. Mean pasture variables grouped by major soil type at each site

Variable	Soil groups						
	Uc	Um	Gn	Dy	Dr	Db	Uf
n =	11	6	9	25	20	23	13
Plant density (m^{-2})	44.6	41.8	48.2	50.0	41.6	57.5	48.0
Projected cover rating	4.4	3.5	3.8	4.0	4.0	4.1	4.3
Crown cover (%)	1.3	1.6	1.3	2.1	1.3	1.5	1.6
Tree basal area (m^2 ha^{-1})	9.0	8.3	4.6	8.6	5.3	4.9	3.1

Table 4. Mean frequency of 58 consolidated pasture taxa on various soil types in central, inland Queensland

The soil order (left to right) is from the most sandy, freely draining soils to the most clayey, heavy-textured types, with the intervening ones being generally of increasingly better fertility from left (Dy) to right (Db). Plant groups (A1, A2, etc.) are from QGraze categories. *$P < 0.05$ among soil types

Group	Taxon	Soil groups Uc	Um	Gn	Dy	Dr	Db	Uf	Level of significance	Number of sites
	Key grasses									
A1	*Astrebla* spp.	0	0	2	0	0	4	12	–	3
A1	*Bothriochloa bladhii*	0	10	22	20	13	26	36	–	34
A2	*Bothriochloa decipiens*	6	13	28	34	29	34	13	–	60
A1	*Bothriochloa ewartiana*	22	0	36	0	33	9	44	–	25
A1	*Cenchrus ciliaris*	12	44	4	4	35	21	16	–	32
A1	*Chrysopogon fallax*	44	20	26	34	30	28	24	–	100
A1	*Dichanthium sericeum*	3	6	19	11	8	20	36	*	47
A1	*Eremochloa bimaculata*	16	29	2	33	13	54	0	–	40
A2	*Eriochloa* spp.	12	3	11	4	6	11	15	–	35
A1	*Heteropogon contortus*	37	10	18	27	33	17	38	–	70
A1	*Themeda triandra*	56	0	14	10	7	9	13	–	33
A1, 2, 3	*Urochloa* spp.	0	0	4	0	5	0	10	–	8
	Other grasses									
A2	Aristida1 – branched seedhead, no awn column	23	26	38	32	20	13	21	*	91
A2	Aristida2 – on clay soils	0	0	6	2	5	25	35	–	17
A2	Aristida3 – unbranched seedhead, no awn column	17	27	13	22	12	9	6	–	59
A3/A2	Aristida4 – long twisted awn column	14	15	24	14	6	2	2	–	29
A2	*Aristida latifolia*	0	0	0	0	2	10	9	–	12
A2	*Austrostipa* spp.	0	4	2	2	12	2	0	–	6
A2	*Bothriochloa pertusa*	0	0	0	0	10	0	0	–	2
A2	*Chloris divaricata*	6	28	11	12	6	27	23	*	48
A2	Other *Chloris* spp.	0	3	0	9	8	5	18	*	32
A2	*Cymbopogon* spp.	4	6	2	9	20	8	6	–	49
A2	*Cynodon* spp.	0	0	0	2	0	0	4	–	2
A2	*Digitaria brownii*	7	10	5	4	7	4	6	–	32
A2	*Digitaria divaricatissima*	2	17	10	6	6	11	9	–	38
A2	Other *Digitaria* spp.	6	15	3	12	8	2	2	–	30
A2	*Enneapogon* spp.	5	11	32	6	14	17	25	*	74
A2	*Enteropogon acicularis*	5	8	9	5	9	5	5	–	26
A2	*Enteropogon ramosus*	0	0	38	17	0	10	2	–	7
A2	*Eragrostis lacunaria*	10	30	11	16	7	6	3	–	46
A2	*Eragrostis molybdea*	9	8	4	8	19	21	4	–	39
A2	Other *Eragrostis* spp.	9	8	2	14	8	7	0	–	57
A2	*Eriachne* spp.	7	2	9	0	5	6	24	–	16
A2	*Eulalia aurea*	3	7	3	6	5	6	5	–	37
A2	*Melinis repens*	8	0	2	0	11	2	11	–	9
A2	*Panicum effusum*	12	5	9	5	6	11	5	*	63
A2	Other *Panicum* spp.	0	0	3	5	2	3	7	*	26
A2	*Paspalidium* spp.	4	17	2	14	7	6	8	–	33
A2	*Setaria* spp.	7	6	0	17	0	0	0	–	9
A2/A3	Sporobolus1	0	4	10	3	16	10	18	–	28
A2	Sporobolus2	17	8	22	12	6	13	13	–	50
A2	*Tripogon loliiformis*	6	8	23	16	24	34	26	–	62
A2	Other perennial grasses	4	4	5	5	4	6	0	–	34
	Annual grasses									
A3	*Brachiaria* spp.	65	4	4	24	3	0	0	–	13
A3	*Tragus australianus*	2	4	19	3	13	14	26	–	42
A3	Other annual grasses	21	19	4	12	11	10	10	–	31
	Other monocotyledons + ferns									
Bs	Cyperaceae	31	21	16	30	28	26	15	–	94
Bl	Liliaceae	0	0	0	0	2	0	2	–	3
Bf	Pteridophyta	12	3	0	10	7	12	2	–	26
Br	Xanthorrhoeaceae	19	3	0	8	4	3	10	–	24

(*continued next page*)

Table 4. (*continued*)

Group	Taxon	Soil groups Uc	Um	Gn	Dy	Dr	Db	Uf	Level of significance	Number of sites
					Dicotyledons					
Ca	Asteraceae	6	22	5	13	13	3	24	*	52
Co	*Brunoniella australis*	13	3	15	17	9	17	20	–	65
Cc	Chenopodiaceae	0	2	0	0	21	18	17	–	23
Cm	Malvaceae	5	18	19	8	14	15	15	–	64
Cl	Non-toxic Leguminosae	30	17	10	20	5	9	12	*	65
Cl	Potentially toxic Leguminosae	6	2	6	3	15	7	11	–	36
Cs	Succulents	0	2	14	2	7	10	4	–	29
Co	Other forbs	11	20	16	10	16	25	21	*	86

Table 5. Mean pasture variables grouped by estimated pasture condition of each site

Pasture condition was assessed by experienced native pasture researchers using the system devised by Tothill and Gillies (1992), which combines abundance of desirable perennial grasses with extent of visible erosion features (see text for details). Number of sites in each condition category also shown. Tree basal area was estimated using the Bitterlich method (Grosenbraugh 1952)

Variable	Estimated pasture condition A+	A	A–	B+	B	B–	C+	C
n =	6	11	16	20	10	30	7	7
Plant density (m^{-2})	41.0	40.7	53.4	41.6	52.1	56.8	32.2	53.4
Dry matter yield rating	2.5	2.6	2.5	2.2	2.5	2.0	1.9	1.5
Projected cover rating	4.8	4.8	4.4	3.9	4.5	3.7	3.5	3.1
Crown cover (%)	2.0	1.8	2.0	1.7	1.7	1.4	1.0	0.7
Tree basal area (m^2 ha^{-1})	8.6	8.4	7.7	6.6	4.3	4.6	2.0	2.8

Table 6. Number of sites, classified by either soil type or pasture condition within each of the three overstorey tree categories (see text for details of soil types and condition assessments)

	Overstorey tree group Narrow-leaved ironbark	Silver-leaved ironbark	Poplar box
		Soil type	
Uc	7	1	3
Um	4	1	1
Gn	2	4	3
Dy	6	4	15
Dr	3	8	9
Db	3	7	13
Uf	1	5	7
		Condition	
A+	1	3	2
A	4	0	7
A–	4	4	8
B+	5	8	7
B	2	3	5
B–	9	6	15
C+	0	2	5
C	1	4	2
C–	0	0	0

mean erosion rating was compared with the overall site condition rating ($r = 0.3$) even though assessors assigned poorer condition ratings where soil erosion was obvious. The transformation of category data into an intuitive numeric series of values that reflect desirability of a feature seems to have worked very well for surface type and cryptogam cover ratings judging by the high correlation coefficient (Table 2).

There was no strong correlation between the plant density and standing pasture DM rating, projected ground cover or living crown cover, based on some 5000 quadrats (Table 2). McIvor (1998) also found no correlation between plant density and herbage yield in speargrass pastures in the Charters Towers district of north Queensland. No correlation existed either between living crown cover and projected ground cover of pasture plus litter ($r = 0.143$). This is disappointing because projected ground cover, which can be remotely sensed with some confidence (Pickup *et al*. 1993), cannot be used therefore as a simple substitute for living crown cover, which is a very important pasture and land condition attribute but tedious to measure accurately. There was a positive correlation, however, between the standing pasture DM rating and projected ground cover rating ($r = 0.54$) as the well-tested pasture growth model GRASP would suggest (Littleboy and McKeon 1997). The positive relationship was expected but absolute standing pasture DM might not always be as well correlated with living pasture crown cover as this survey suggests ($r = 0.564$) if used to compare large areas in different locations with differing recent grazing management or rainfall. This is because grazing can quickly reduce herbage mass without a change to the crown cover of pastures, and conversely, storm rains quickly regrow pastures in early summer from the existing live grass crowns.

Soil type effects on pastures

Soil profile type had no consistent effect on mean plant density, projected ground cover or percent crown cover

Table 7. Percentage of each soil type in each pasture condition class plus percentage of each condition class and soil type among all the sites (see text for details of soil types and condition assessments)

Notably high percentages of an assessed condition category are highlighted

Assessed condition	Soil profile type Uc	Um	Gn	Dy	Dr	Db	Uf	By condition
A+	0	0	0	17	33	33	17	6
A	18	0	9	**55**	9	9	0	10
A–	6	0	0	**44**	19	25	6	15
B+	25	5	20	15	10	10	15	19
B	10	10	0	20	10	**40**	10	9
B–	7	10	10	20	10	27	17	28
C+	0	0	0	0	**71**	14	14	7
C	0	14	14	0	**43**	14	14	7
By soil	10	6	8	23	19	21	12	–

(Table 3). However, lower fertility soils tended to have a greater mean tree basal area among the surveyed sites. Existing tree stem area (m^2 ha^{-1}) was generally lower on heavier soils (Table 3) probably because clearing such sites is perceived as more profitable but it could also be linked to faster tree regrowth rates on lighter soils. The trend for poorest condition pastures to be on the most heavily cleared areas (Table 5) may indicate an unrealistically high perceived carrying capacity by producers after clearing woodlands.

Soil preferences of species

The mean frequency of the 58 consolidated plant guilds on the different soils (Table 4) was mostly in line with our previously unquantified state of knowledge (Silcock 1993). The soil type order (left to right) in Table 4 is from the most sandy, freely draining soils to the most clayey, heavy-textured types, with the intervening ones being generally of increasingly higher fertility from left (Dy) to right (Db). The plant group categories are from the QGraze program where A1 is key perennial grasses, A2 is other perennial grasses, B is the non-grass monocots plus ferns, and C is broad-leaf dicotyledons with various sub-groups nominated therein. Some guilds, such as *Urochloa* spp., include more than one grass category.

The clay soil Aristida2 group, *Aristida leptopoda* (whitespear) and *A. platychaeta* (curly wiregrass), were very common on clayey soils and absent from sands and shallow loams. *Bothriochloa decipiens* (pitted bluegrass) was most common on loams and earths whereas *Chrysopogon fallax* (golden-beard grass) showed no soil type preference. Cyperaceae (small sedges, Bs), often regarded as wetland species, were common on all soil types as was *Heteropogon contortus* (black speargrass), except on the lithosols (Um soils). Sporobolus1 guild (branched seed-headed, perennial dropseed grasses *Sporobolus caroli* and *S. actinocladus*) were not found on deep sandy soils (Uc) and *Eremochloa bimaculata* (poverty grass) was not recorded from clays (Uf). Many guilds had no strong soil preference but some, such as *Panicum effusum* (hairy panic), *Chloris divaricata* (slender windmill grass) and Asteraceae (daisies), had significantly different ($P < 0.05$) frequency of occurrence on certain soils (Table 4). However, the number of sites involved for a soil type is sometimes small (only six Um soils, Table 6) so that confidence cannot be held for some of the differences.

Pasture condition versus cover ratings

Pasture condition at a site was positively related to mean standing pasture DM rating ($r = 0.57$), projected ground cover ($r = 0.58$), pasture crown cover ($r = 0.35$) and tree basal area ($r = 0.32$). The first three correlations were expected but the biological significance of a moderate correlation between pasture condition and tree basal area is uncertain because it is confounded with soil clay content. The poorest condition pastures were generally found on the most heavily cleared or naturally sparsely timbered areas (Table 5) and these were from sites with heavier-textured soils (Dr, Db and Uf) (Table 3). Conversely, narrow-leaved ironbark sites, which were mostly well timbered, occurred on soils with a more sandy surface and no strong sub-surface clay horizon development – Uc, Um and Gn (Silcock *et al*. 1996). Total plant density of the five main pasture species present at a site was not well correlated ($r = -0.15$) with pasture condition. Very poor condition *Aristida/Bothriochloa* pastures (C and C–, seven recorded sites) were probably not as common in central Queensland in the mid-1990s as the desktop audit in 1992 by Tothill and Gillies (1992) had suggested. The unfavourable seasons, however, meant we were unable to sample some drought-stricken sites that appeared to be in low C condition.

Table 5 indicates that an *Aristida/Bothriochloa* pasture with a ground cover rating of less than 4 out of 6 and crown cover estimate below 2% is in danger of degenerating into a poor pasture and potentially suffering major soil loss. All three vegetation groups had a similar rating of ~4 (30–50% cover) for pasture ground cover (Table 6 in Silcock *et al*. 2015). This was a surprisingly high value after a relatively dry period (Long Paddock 2014).

Comparisons when using three tree overstorey types

Among the three tree overstorey groups, the narrow-leaved ironbark sites were predominately on coarse or shallow soils (Table 6) and the poplar box sites occurred mainly on soils with higher clay content, as expected. Soil type did not clearly separate the poplar box and silver-leaved ironbark groups although neither was common as the dominant tree on sandy soils. The lack of differentiation based on broad soil type was unexpected in view of the importance placed on them individually for describing Queensland land types in grazing management educational packages (FutureBeef 2014).

Pasture condition versus soil type

Our attempt to sample sites in a wide range of pasture condition was moderately successful (Table 6) although we did not sample any C– sites. Thirty-one percent of sites were assessed as being in A condition, 56% in B condition and 13% in C condition. This is a greater proportion of A-condition pasture than the 20% believed to exist around that time for equivalent local pasture units (Tothill and Gillies 1992). The C-condition sites were concentrated on the Dr soils (duplex soil profile with a reddish clay sub-soil) whereas a relatively high proportion on Dy soils were rated as A condition (Table 7). There was only one C-condition site in the narrow-leaved ironbark vegetation type. Perhaps this reflects the smaller degree of tree clearing, and the lower selective grazing pressure placed by free-ranging stock on such low mineral-content pastures (Gramshaw 1995).

Table 8. Mean frequency of 58 consolidated pasture taxa in *Aristida/Bothriochloa* pastures of different pasture condition classes in central Queensland

*$P < 0.05$, among condition classes

Group[A]	Taxon or guild	Pasture condition class A+	A	A–	B+	B	B–	C+	C	Significant difference
					Key grasses					
A1	*Astrebla* spp.	0	2	0	0	4	12	0	0	–
A1	*Bothriochloa bladhii*	5	36	35	16	9	24	0	16	–
A2	*Bothriochloa decipiens*	33	26	48	15	36	25	6	13	*
A1	*Bothriochloa ewartiana*	34	0	54	40	0	24	9	28	–
A1	*Cenchrus ciliaris*	51	6	2	22	26	5	40	43	–
A1	*Chrysopogon fallax*	32	23	36	27	26	34	23	36	–
A1	*Dichanthium sericeum*	9	27	10	19	46	20	18	22	–
A1	*Eremochloa bimaculata*	8	31	39	11	42	26	0	55	–
A2	*Eriochloa* spp.	10	8	8	10	4	14	11	0	–
A1	*Heteropogon contortus*	63	46	20	27	25	28	10	12	–
A1	*Themeda triandra*	20	16	10	17	5	11	4	3	–
A1, 2, 3	*Urochloa* spp.	2	4	0	8	0	4	0	8	–
					Other perennial grasses					
A2	Aristida1	5	29	25	28	18	28	16	8	*
A2	Aristida2	8	6	16	26	38	27	40	2	–
A2	Aristida3	30	19	14	17	26	10	9	5	–
A3/A2	Aristida4	0	27	6	11	9	13	14	0	–
A2	*Aristida latifolia*	2	0	2	6	14	7	16	0	–
A2	*Austrostipa* spp.	0	2	2	2	0	3	12	0	–
A2	*Bothriochloa pertusa*	0	0	0	0	0	16	0	4	–
A2	*Chloris divaricata*	2	16	10	23	29	19	7	4	–
A2	Other *Chloris* spp.	17	8	10	2	4	6	8	4	–
A2	*Cymbopogon* spp.	33	10	10	3	6	5	0	16	*
A2	*Cynodon* spp.	0	0	0	0	0	3	0	0	–
A2	*Digitaria brownii*	9	6	4	8	3	6	2	2	–
A2	*Digitaria divaricatissima*	2	8	9	7	9	10	2	0	–
A2	Other *Digitaria* spp.	8	7	7	9	13	7	0	0	–
A2	*Enneapogon* spp.	14	8	14	16	16	24	12	8	–
A2	*Enteropogon acicularis*	24	6	5	4	2	7	5	10	–
A2	*Enteropogon ramosus*	4	38	30	0	4	12	0	0	–
A2	*Eragrostis lacunaria*	12	7	13	20	5	7	4	16	–
A2	*Eragrostis molybdea*	0	14	10	11	24	20	6	6	–
A2	Other *Eragrostis* spp.	7	14	13	6	13	9	6	7	–
A2	*Eriachne* spp.	0	0	12	9	0	10	8	4	–
A2	*Eulalia aurea*	7	5	5	6	4	5	6	8	–
A2	*Melinis repens*	4	0	0	9	0	2	34	2	–
A2	*Panicum effusum*	8	10	8	7	6	9	3	3	–
A2	Other *Panicum* spp.	6	5	2	5	6	4	2	2	–
A2	*Paspalidium* spp.	31	6	10	9	9	4	2	14	–
A2	*Setaria* spp.	0	28	6	17	5	8	0	0	–
A2/A3	Sporobolus1	2	10	5	10	5	15	20	13	–
A2	Sporobolus2	3	9	20	18	10	8	34	4	*
A2	*Tripogon loliiformis*	14	18	15	12	21	27	23	48	–
A2	Other perennial grasses	8	5	3	5	3	4	6	6	–
					Annual grasses					
A3	*Brachiaria* spp.	0	34	74	2	44	11	2	0	–
A3	*Tragus australianus*	6	0	3	10	0	18	21	11	–
A3	Other annual grasses	2	2	14	13	3	23	3	16	–
					Other monocotyledons + ferns					
Bs	Cyperaceae	30	39	26	24	21	28	9	24	–
Bl	Liliaceae	0	2	2	2	0	0	0	0	–
Bf	Pteridophyta	10	15	4	17	6	12	2	0	–
Br	Xanthorrhoeaceae	3	12	10	16	2	4	0	2	–

(*continued next page*)

Table 8. (*continued*)

Group[A]	Taxon or guild	Pasture condition class A+	A	A–	B+	B	B–	C+	C	Significant difference
					Dicotyledons					
Ca	Asteraceae	4	6	9	11	18	11	46	12	*
Co	*Brunoniella australis*	12	14	16	15	14	18	2	13	–
Cc	Chenopodiaceae	0	0	4	2	5	19	18	37	–
Cm	Malvaceae	6	4	7	16	3	16	22	20	*
Cl	Non-toxic Leguminosae	22	4	18	15	8	14	4	5	–
Cl	Potentially toxic Leguminosae	11	0	6	6	5	12	10	17	–
Cs	Succulents	3	14	2	15	6	6	6	8	–
Co	Other forbs	12	18	10	19	16	21	11	21	–

[A]QGraze groups as for Table 4.

Table 9. Plant species of *Aristida/Bothriochloa* pastures that could have indicator status for pasture condition under each of the three main overstorey tree types (NL ironbark, SL ironbark and Poplar box)

Recs is the number of sites where taxon or group recorded; and Indic. is a taxon or group that could have possible indicator status (incr is an increaser, decr is a decreaser and mid is a parabolic frequency response). Major taxa that lack predictive value are also shown for completeness

Taxon or group	NL ironbark 26 sites Recs	Indic.	SL ironbark 30 sites Recs	Indic.	Poplar box 51 sites Recs	Indic.
Aristida1 – branched seedhead, no awn column	26	incr	23	mid	42	decr?
Aristida2 – from clay soils	0	–	6	mid	11	incr
Aristida3 – unbranched seedhead, no awn column	15	–	14	–	30	decr
Asteraceae	15	incr?	13	–	24	–
Bothriochloa bladhii	2	–	11	–	21	decr?
Bothriochloa decipiens	11	–	14	incr	35	decr
Bothriochloa ewartiana	1	–	15	–	9	mid
Brunoniella australis	13	–	20	incr	32	–
Cenchrus ciliaris	7	–	6	incr?	19	incr?
Chenopodiaceae	2	–	4	incr?	17	incr
Chloris divaricata	1	–	10	mid	37	–
Other *Chloris* spp.	6	–	8	–	18	decr
Chrysopogon fallax	24	–	28	–	48	–
Cymbopogon spp.	18	decr	10	–	21	decr
Cyperaceae	23	–	23	–	48	decr?
Dichanthium sericeum	4	–	18	decr	25	–
Digitaria divaricatissima	9	–	6	–	23	mid
Other *Digitaria* spp.	13	–	4	–	13	decr
Enneapogon spp.	14	–	23	–	37	–
Eragrostis molybdea	5	–	10	incr?	24	mid?
Eremochloa bimaculata	17	–	9	–	14	–
Eriochloa spp.	7		9	incr	19	–
Heteropogon contortus	17	decr	28	decr	25	–
Malvaceae	12	–	17	–	35	incr
Non-toxic Leguminosae	14	–	24	decr?	27	decr
Potentially toxic Leguminosae	4	–	18	incr?	14	–
Panicum effusum	16	–	19	decr	28	–
Themeda triandra	4	–	13	decr	15	decr
Tragus australianus	7	–	16	incr	19	incr
Tripogon loliiformis	10	–	13	–	39	incr?
Sporobolus2	15	–	9	decr	26	–
Succulents	1	–	8	–	20	–

The Dr soils that had a high proportion of C-condition sites are characterised by easily scalded surfaces that do not grow vigorous *Aristida* spp. that, in a heavily grazed pasture, would help maintain a higher ground cover. By contrast, the high proportion of A-condition sites on the Dy (yellow duplex) soils (Table 7) is probably because they are cleared less, not close to riparian zones and thus least subjected to regular heavy grazing by free-ranging stock.

Species frequency versus pasture condition

Frequency of *C. fallax* was unrelated to site condition, contrary to the experience of Wandera *et al*. (1993) in *H. contortus* pastures. Also unrelated to pasture condition was the frequency of the common plants, *B. australis*, *C. ciliaris*, *Dichanthium sericeum* (Queensland bluegrass) and *E. bimaculata* (Table 8). Thus, use of these easily identifiable species as indicators of pasture condition in *Aristida/Bothriochloa* pastures needs further consideration and study. An abundance of the perennial grasses *D. sericeum* and *C. ciliaris* is usually regarded as an indication of good pasture condition (Tothill and Gillies 1992) and recent enhancements to the GRASP pasture growth model by Scanlan *et al*. (2014) strongly links percentage of perennial grasses to the growth potential and condition of tropical pastures. Hence, defining which grasses are classed as perennials and which are not when estimating pasture stability and resistance to grazing and fire is a future challenge. The mean frequency of all plant guilds for each nominal pasture condition class is shown in Table 8. In some cases (A+, C+ and C condition), the number of sites available to generate the means is low (Table 6), so no statistically reliable conclusions can be drawn for those cases. Species showing apparent trends with changing pasture condition include *B. decipiens*, Asteraceae species and Malvaceae species (Table 8). That trend is commonly accepted for the Malvaceae but not so readily for *B. decipiens*. In some cases the trend is parabolic rather than linear, for example Aristida1 guild.

Multiple regression analysis found that the individual variables most highly correlated with assessed pasture condition, such as crown cover and standing pasture DM rating, maintained their high predictive capacity in a multi-dimensional array. The inclusion of individual species, for example *D. sericeum*, or species groups, such as *Enneapogon* spp., provided only minor extra discrimination towards a mathematical justification of a condition score. A combination of projected ground cover, mean quadrat standing pasture DM rating and tree basal area had an R^2 value with site condition of 0.51 ($P < 0.05$). The inclusion of further data about the abundance of key pasture species, such as *Tripogon loliiformis* (five-minute grass) and *D. sericeum*, only improved the R^2 value marginally to 0.54.

Increaser/decreaser pasture species

Increaser species, i.e. species that increase in frequency as pasture condition declines under excessive grazing (Dyksterhuis 1949), were found to be Asteraceae, potentially toxic Leguminosae, such as *Indigofera* and *Crotalaria* spp., Malvaceae and *Tragus australianus* (small burrgrass). Apparent decreaser species were *H. contortus*, non-toxic Leguminosae, for example *Glycine* spp. and *Cullen* spp., and *Themeda triandra* (kangaroo grass). Some taxa had a parabolic frequency response when viewed against pasture condition. This would indicate a low ability to compete with vigorous, perennial grasses (A+ condition) and a lack of persistence in heavily overutilised or eroded pastures (C condition). *Aristida calycina* (dark wiregrass) from the Aristida1 guild and the Sporobolus2 guild, such as *Sporobolus elongatus* (slender rat's-tail grass) and *S. creber* (western rat's-tail), fall into this category (Table 8). Despite the commonness of *C. fallax* and *Enneapogon* spp., we were unable to rate either as indicator species for any of the tree overstorey types. *Chloris divaricata* (common in fair to average condition pastures) showed a parabolic frequency response whereas Orr *et al*. (2001) classed it as an increaser on black speargrass pastures in central Queensland.

Some of these taxa are useful indicators only within one of the three tree overstorey groups, for example the Aristida4 guild with long, twisted awn columns were mostly restricted to the coarser, sandy soils (Table 4). Thus a consistent group of indicator species seems most unlikely because soil type has a large influence on species presence and soil type is so diverse in *Aristida/Bothriochloa* pastures as currently defined. *Brunoniella australis* would be called an increaser species in the silver-leaved ironbark community but not on sites with the other two dominant tree overstoreys. *Heteropogon contortus* is normally classed as a decreaser (Orr *et al*. 2001) on speargrass pastures in the east of Queensland and would be also for the narrow-leaved ironbark and silver-leaved ironbark communities but not on the poplar box community. *Aristida* spp. did not show up as classic increaser species in these pastures because their frequency declines in very poor condition pastures; some may even be rated as decreasers on the poplar box sites that were sampled (Table 9).

Increaser species identified here for *Aristida/Bothriochloa* pastures that were not named by Tothill and Gillies (1992) are *T. australianus*, Asteraceae, Malvaceae and the potentially toxic Leguminosae guild (*Indigofera*, *Tephrosia* and *Crotalaria* species). A frequency of over 20% for Malvaceae and Sporobolus2 reflects a very poor condition pasture (Table 8) but, for *T. loliiformis* to indicate poor condition in the poplar box community, its frequency would need to be over 40% because its plants are so small and common. Other data for species whose abundance has a significant correlation with the broad pasture parameters are listed in Table 4 in Silcock *et al*. (2015).

Conclusions

The perceived condition of *Aristida/Bothriochloa* pastures was not readily quantified using projected ground cover as the surrogate metric, yet it was reasonably well correlated with herbage mass. Condition ratings were not well correlated with the abundance of a particular pasture species or guild of species when all *Aristida/Bothriochloa* pastures were included. However, within a tree overstorey type, the data indicate abundance values and ranges that might be applied to common pasture variables when devising condition-class boundaries, such as crown cover and frequency of some minor species. There may be a better chance of using floristic composition to objectively judge condition if data for a range of species with diverse characteristics are pooled, such as for *T. loliiformis*, *T. triandra*, Malvaceae and an appropriate *Aristida* guild. Nevertheless, the cover ratings are still important.

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