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Floristic composition and pasture condition of *Aristida/Bothriochloa* pastures in central Queensland. I. Pasture floristics

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Abstract. A survey was conducted in central inland Queensland, Australia of 108 sites that were deemed to contain *Aristida/Bothriochloa* native pastures to quantitatively describe the pastures and attempt to delineate possible sub-types. The pastures were described in terms of their floristic composition, plant density and crown cover. There were generally ~20 (range 5–33) main pasture species at a site. A single dominant perennial grass was rare with three to six prominent species the norm. *Chrysopogon fallax* (golden-beard grass) was the perennial grass most consistently found in all pastures whereas *Aristida calycina* (dark wiregrass), *Enneapogon* spp. (bottlewasher grasses), *Brunoniella australis* (blue trumpet) and *Panicum effusum* (hairy panic) were all regularly present. The pastures did not readily separate into broad floristic sub-groups, but three groups that landholders could recognise from a combination of the dominant tree and soil type were identified. The three groups were *Eucalyptus crebra* (narrow-leaved ironbark), *E. melanophloia* (silver-leaved ironbark) and *E. populnea* (poplar box). The pastures of the three main sub-groups were then characterised by the prominent presence, singly or in combination, of *Bothriochloa ewartiana* (desert bluegrass), *Eremochloa bimaculata* (poverty grass), *Bothriochloa decipiens* (pitted bluegrass) or *Heteropogon contortus* (black speargrass). The poplar box group had the greatest diversity of prominent grasses whereas the narrow-leaved ironbark group had the least. Non-native *Cenchrus ciliaris* (buffel grass) and *Melinis repens* (red Natal grass) were generally present at low densities.

Describing pastures in terms of frequency of a few species or species groups sometimes failed to capture the true nature of the pasture but plant abundance for most species, as density, herbage mass of dry matter or plant crown cover, was correlated with its recorded frequency. A quantitative description of an average pasture in fair condition is provided but it was not possible to explain why some species often occur together or fail to co-exist in *Aristida/Bothriochloa* pastures, for example *C. ciliaris* and *E. bimaculata* rarely co-exist whereas *Tragus australianus* (small burrgrass) and *Enneapogon* spp. are frequently recorded together. Most crown cover was provided by perennial grasses but many of these are *Aristida* spp. (wiregrasses) and not regarded as useful forage for livestock. No new or improved categorisation of the great variation evident in the *Aristida/Bothriochloa* native pasture type can be given despite the much improved detail provided of the floristic composition by this survey.

Additional keywords: *Chrysopogon fallax*, crown cover, herbage mass, indicator species, plant density, sedges.

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Introduction

Native pastures in northern Australia have been grouped into 27 major types (Tothill and Gillies 1992) based on a combination of vegetation structures, for example woodlands, shrublands and grasslands and soil type, based on the soil series of the Atlas of Australian Soils (Isbell *et al*. 1967). One major type is classified as *Aristida/Bothriochloa* pastures. They exist in a variety of eucalypt woodlands on non-cropping soils across northern Australia and normally have no single dominant pasture grass. The *Aristida* (wiregrass) and *Bothriochloa* (bluegrass) species are common but little quantitative pasture data exists. Floristic descriptions of this pasture community are generally limited to lists of species that occur (Story *et al*. 1967; Beeston 1978). A limited pasture survey was conducted by Schefe *et al*. (1993) but no other data was provided about the condition of those pastures or of the soil surface. Twenty years later, there are now ~30 land types described in central Queensland that are essentially *Aristida/Bothriochloa* native pastures (FutureBeef 2014).

In Queensland, Tothill and Gillies (1992) retained the pasture map units developed by Weston *et al*. (1981) and identified 15 sub-units (Local Pasture Units 41–55) of the *Aristida/Bothriochloa* pasture type. Seven of their units occur in central Queensland (Local Pasture Units 47–53) and they grade into black speargrass (*Heteropogon contortus*) pastures to the east and gidgee (*Acacia cambagei*), spinifex (*Triodia* spp.) or mulga (*Acacia aneura*) pastures to the west. These adjoining lands have been extensively researched in the past, in marked contrast to the *Aristida/Bothriochloa* pastures until recently (O'Reagain and Bushell 2011). Weston *et al*. (1981) mapped over 10 million ha of *Aristida/Bothriochloa* pastures in central Queensland between Surat (27.2°S) in the south and Belyando Crossing (21.6°S) in the north, i.e. ~53% of the total land surface of the region (Silcock *et al*. 1996). Only 4.5% of this area had the potential to grow arable crops, 10% lies in State Forests and less than 1% was in National Parks in the mid-1990s (Silcock *et al*. 1996). Much of the *Aristida/Bothriochloa* pastures in central Queensland are excellent for beef cattle breeding.

The main Local Pasture Units of Tothill and Gillies (1992) in central Queensland were assessed by consensus of experienced people as having 20% of the pastures in A condition, 50% in B condition and 30% in C condition in ~1991. 'A' condition means minimally degraded as grazing land; 'B' condition means degraded but not so far that prudent grazing management could not return it to A (good) condition, and 'C' condition means expensive rehabilitation procedures would be needed to restore the land to even B condition. However, there was no quantitative data to guide the management changes needed to rehabilitate some of the *Aristida/Bothriochloa* pastures in poor condition. O'Reagain *et al*. (2014) have since provided important data towards this end and Scanlan *et al*. (2014) have modified the GRASP model for tropical bunchgrass pastures to reflect that improved knowledge. Tothill and Gillies (1992) provided a 'best guess' assessment of what the dominant grasses were for pastures in A, B and C condition of each Local Pasture Unit. Common dominants named for A-condition pasture were *Bothriochloa decipiens* (pitted bluegrass), *Cymbopogon refractus* (barbwire grass), *Chrysopogon fallax* (golden-beard grass) and *Dichanthium affine* (slender bluegrass), whereas *Aristida* spp., *Chloris* spp. and *Eragrostis* spp. (lovegrasses) were said to dominate most C-condition pastures.

The need to rely on opinion highlights the need for improved resource and grazing management information about this undulating to steeply sloping country on erodible duplex soils in central Queensland. As a consequence, a study was conducted to provide quantitative data to assist in the sustainable land use of the headwaters of three major river catchments, the Burdekin, Fitzroy and Darling Rivers. The first step was a survey to:

- describe the botanical composition of pasture in different condition;
- merge the diverse pasture types into a small number of land management units, if possible; and
- identify key species and indicators of different condition states.

This paper and that of Silcock *et al*. (2015) report on the outcomes of the survey by competent native pasture specialists. In this paper the botanical composition of the pastures plus related vegetation measures – tree stem area, pasture living crown cover, projected ground cover and plant density – are reported. The paper of Silcock *et al*. (2015) groups sites by major soil profile type and assessed condition, and then relates them to pasture variables and soil surface features such as erosion signs, cryptogams, litter cover and crust hardness.

Methods

Site selection was undertaken in the field by experienced native pasture agronomists. No clear guidelines to separate *Aristida/Bothriochloa* pastures from adjacent black speargrass and other pasture types were provided by Tothill and Gillies (1992) nor by Weston *et al*. (1981) who used the soil series polygons of the Australian Soils Atlas (Isbell *et al*. 1967).

Between May 1993 and June 1995, 108 sites were surveyed using a standardised procedure to record pasture, tree and soil data. Sites were located in a rhomboid-shaped zone bounded roughly by Lake Galilee (22.3°S, 145.8°E), Moranbah (22.0°S, 148.0°E), Chinchilla (26.7°S, 150.6°E) and Roma (26.6°S, 148.8°E). Among the sites were 19 groups of 2–3 adjacent paddocks with visible differences in perceived condition induced by management or timber clearing, which were deliberately chosen to test for differences in pasture composition. A 'site' was 100×300 m with even timber and ground cover in the mid-slope part of a landscape and away from infrastructure such as roads, waterpoints and fences. Site estimates were made of tree basal area (Bitterlich stick method – Grosenbraugh 1952), shrub canopy cover, pasture condition, using the descriptions of Tothill and Gillies (1992), and the nature of timber clearing which had occurred in the past. Tothill and Gillies (1992; Table 2) use a two-way matrix of soil surface erosion features and proportion of desirable pasture species to assign a pasture condition. Our detailed pasture data were collected using fifty 0.25 m^2 quadrats (square, thin metal frames laid on the ground) evenly distributed across each site. Other research has shown that this is a sufficient number of quadrats of that size to gain an adequate assessment of pasture cover and composition across a simple landscape element (QGraze 1994; Tongway 1994).

Data recording

Basic site information recorded was the location, soil type, tree and shrub species density, pasture condition and recent management history. Palm-top computers with a prepared electronic data capture program recorded pasture composition and soil surface ratings. The floristic data was recorded using the codes and classifications of the QGraze monitoring program (QGraze 1994). For each quadrat, the following pasture parameters were recorded:

- Herbage mass of dry matter rating (0–5, relative scale for 0.25 m^2),
- Projected ground cover (0–6, QGraze scale),
- Estimated total living pasture crown cover (%) at ground level,
- Name of the five most common pasture species, by herbage mass,
- Percentage of the total crown cover and number of plants in the quadrat for each of the five most common species. Where a diffuse sward existed for a species, a code of 99 was used for

numbers and was enumerated as one plant when pasture density was calculated.

- Other key *Aristida/Bothriochloa* pasture species from the QGraze list that were not among the five most common in a quadrat.

From this raw data, we calculated for each site:

(*a*) species frequency,
(*b*) a minimum plant density of each species and the whole pasture,
(*c*) the contribution (%) of each species to total pasture crown cover, and
(*d*) total live pasture crown cover (%) for the site.

The herbage mass of dry matter rating was used to assess the spatial variability of herbage mass across the site. An absolute value, though visually assessed and recorded, was not used in the data analysis. The live crown cover was visually estimated by the operators who mentally compacted the live crown areas within each quadrat and assigned a percentage cover with the guidance of a set of circular discs that represented 0.5%, 1%, 2%, 3%, 5% and 10% of the quadrat area.

Other details about the data collected are shown in Appendices 1 and 2 of Silcock *et al*. (1996) and are available from the senior author.

Data analyses

Data tabulation and aggregation

The data were collated in cross-tabulated spreadsheets as shown in table 3.1.1 of Silcock *et al*. (1996). Data for related species and plant guilds were also aggregated to look for broad patterns that the diversity due to individual species could be masking, for example annual grasses, chenopods (Chenopodiaceae) and herbaceous legumes (Leguminosae). Groups and species showing promise for site discrimination or grouping were subjected to correlation analysis using the statistical software GENSTAT (GENSTAT 2013). Broad plant types presented in the tables were taken from the QGraze system (QGraze 1994), namely:

A – grasses;
B – other monocots (grass-like plants and lilies) and the ferns (Pteridophyta); and
C – dicotyledons (broad-leafed plants, usually taprooted).

Within these there were sub-groups:

A1 – key desirable perennial grasses;
A2 – other perennial grasses;
A3 – annual grasses;
Ca – Asteraceae (daisies);
Cc – Chenopodiaceae (chenopods, saltweeds);
Cl – herbaceous legumes;
Cm – Malvaceae (flannel weeds and their relatives);
Cs – succulents (Aizoaceae and Portulacaceae); and
Co – other dicotyledon families not included in the other C sub-groups.

Species groups

Taxonomically related species can often be grouped together ecologically and functionally as guilds (de Kroon and Olff 1995). Our taxonomic nomenclature followed Henderson (1997), which applied at the time of our surveys. We simplified the 300 recorded taxa into 58 guilds (Appendix 1) and these will be followed for the rest of this paper and in Silcock *et al*. (2015). The full list of species and their corresponding 58 grouped taxa appear in Appendix 6 of Silcock *et al*. (1996). Some 'groups' were single important species, for example *Bothriochloa ewartiana* (desert bluegrass), whereas others were made up of numerous taxa, for example other forbs has 59 taxa, many of them recorded at single, but different, sites. These groups were used to search among all sites for associations between them and other pasture variables such as crown cover and plant density.

Site groups

Previous work (Silcock *et al*. 1996) showed no clear pasture composition groupings of the sites despite subjecting data to three different pattern analysis packages so it was decided to group the sites on the three dominant overstorey eucalypt trees encountered, namely narrow-leaved ironbark (*Eucalyptus crebra*), silver-leaved ironbark (*E. melanophloia*) and poplar box (*E. populnea*). Each such overstorey type is mostly restricted to certain landscapes, for example narrow-leaved ironbark on shallow soils in hilly terrain, and is associated with broad soil types, for example poplar box on grey, heavier-textured soils with sodic sub-soils and silver-leaved ironbark on better-drained red coloured soils. They express an underlying biological environment that may also be controlling what herbaceous plants commonly grow there, even when the named tree is only a co-dominant tree (Table 1).

Species correlations

Association among species and plant groups was tested with the frequency data. Correlations between the frequency data and plant density, projected cover and crown cover were also calculated. Such correlation analyses were done using all sites together because site numbers were too few within the three tree groups created to adequately test most species. Multiple regression analyses were also undertaken on data from the major pasture species to determine if their abundance was much better explained when several parameters were used in combination.

Table 1. Number of sites for each of the three major vegetation types chosen, plus major associated trees where the nominated eucalypt was not dominant at the site

Tree group	Number of sites	Other co-dominant trees included
Narrow-leaved ironbark	26 (13)[A]	*Angophora costata*, *Angophora floribunda*, *Callitris glaucophylla*, *Corymbia citriodora*, *Corymbia tessellaris*, *Eucalyptus orgadaphylla*
Silver-leaved ironbark	30 (0)	*Corymbia dichromophloia*
Poplar box	51 (5)	*Acacia pendula*, *Corymbia tessellaris*, *Eucalyptus coolabah*, *Eucalyptus mollucana*

[A]Numbers in brackets are the number of sites in the group where another tree species was dominant.

Results and discussion

The surveys were conducted in the latter part of a prolonged regional drought but only after sufficient local rain had fallen that allowed enough growth for pasture species to be identified. The main species in these pastures are strongly perennial but some ephemeral species may not have regenerated before our recordings were done at some sites.

Over 300 individual species were recorded, but 30–40 species were commonly recorded at a site by our method (data not presented), and many individual species were restricted to a small number of sites. However, when related minor species were grouped into guilds (Appendix 1) the proportion of sites having a particular guild sometimes increased markedly. Cyperaceae (small sedges) and *Eragrostis* spp. (lovegrasses) were recorded at over 75% of the 108 sites and *Aristida* spp. at 101 sites (Table 2). This was an encouraging outcome because pasture agronomists would mostly be able to confidently assign plants to such groups but would not necessarily be able to identify all plants to a species level.

Species composition and pasture cover varied greatly among the sites. No species were found at all sites and only nine species were recorded at over half the sites (Table 2). The mean pasture crown cover was low (1.6%) and reflected the recent drought and the inclusion of sites in poor condition (see Silcock *et al.* 2015). Silcock (1993) suggested that good condition pastures under eucalypt woodland with a relatively open tree cover should have a pasture crown cover over 2.5%. The density of pasture plants averaged over 48 m^{-2} and that of the large tussock grasses, such as *Bothriochloa bladhii* (forest bluegrass), *Themeda triandra* (kangaroo grass) and *H. contortus*, reached surprisingly large values (>10 m^{-2}) at individual sites. The latter probably reflects break-up of crowns during the drought rather than appreciable seedling recruitment in recent times as has been recorded elsewhere by McIntyre and Tongway (2005). It is uncertain, however, what impact drought had on the overall floristic composition reported for these perennial grass-dominated pastures.

Annual plants are often reported to temporarily dominate overgrazed pastures after a drought breaks (Breman and Cissé 1977; Illius and O'Connor 1999) yet the abundance of such plants in this study was mostly low, often with a frequency of 8–15% and providing only 1–4% of the pasture crown cover at a site (Table 2). A site in poor condition, such as the Rubyvale town common, however, had a high frequency of the annuals, *Brachyachne convergens* (42%) and *Sporobolus australasicus* (20%), and a moderate level of the total crown cover due to them of 17.3% compared with the survey mean of 6.2% (Table 2). A low proportion of annual grasses in heavily grazed pastures was also reported by McIntyre and Tongway (2005) from native pastures in south-east Queensland. They commented that this was contrary to previously published models for tropical pastures (McIvor and Scanlan 1994) but perhaps aspects of that preliminary model are not a reliable theoretical construct for many tropical pastures in view of our corroborating results.

Floristic composition

Three sets of inter-related data are presented for the most common 100 species (found at five or more sites) – species frequency, species density and the proportion of the pasture crown cover that major species contributed, are given in Table 2. Of the 300 herbaceous taxa recorded, only 14 species were recorded at more than 45 of the sites. Species with a high mean site frequency (>20%) and occurring at many sites (>45%) were: *C. fallax* (100 sites), *Fimbristylis dichotoma* (spiked fringe-rush) (71 sites), *H. contortus* (70 sites), *Tripogon loliiformis* (five-minute grass) (62 sites), *B. decipiens* (60 sites), and *Dichanthium sericeum* (Queensland bluegrass) (48 sites).

As well as being found at almost all sites, *C. fallax* had a frequency of at least 20% in 61 sites. The other most commonly encountered species were *Aristida calycina* (dark wiregrass), *Panicum effusum* (hairy panic) and *Brunoniella australis* (blue trumpet), all being found at 60 sites. The important perennial forage grass, *B. ewartiana*, was only recorded at 25 sites, mostly in the northern areas, which indicates that it may have some specific climatic or soil requirements within its wider recorded range. *Heteropogon contortus* was commonly recorded as an important contributor at many sites (Table 2) despite the land unit being classified by the surveyors as an *Aristida/Bothriochloa* pasture community. Other native species that regularly contributed to these highly diverse pastures were *B. bladhii*, *Aristida jerichoensis* (Jericho wiregrass), *Eremochloa bimaculata* (poverty grass), *Tragus australianus* (small burrgrass), *Chloris divaricata* (slender windmill grass), *Eragrostis molybdea* (granite lovegrass) and *Glycine tabacina* (glycine pea) (Table 2).

At individual sites, it was common for one or two species to be far more abundant than 'normal' and in some cases to far exceed all the other pasture plants in terms of crown cover, for example 80% for *B. bladhii* at one site and 55% for *T. triandra* at another (Table 2). *Cenchrus ciliaris* was the main exotic pasture species recorded (32 sites) and its mean frequency was 21% at those sites. By comparison, the exotic *Bothriochloa pertusa* (Indian couch) was rarely recorded in this survey (two sites).

Aristida spp. were common (at 101 sites) but their average crown cover contribution was only 13.4% of the total but could be as high as nearly 50% at specific sites (Table 2). Hence it would seem that their apparent importance in *Aristida/Bothriochloa* pasture is because of their low preference by livestock giving rise to a very visible presence. Nonetheless, they provided an average of over 3 plants m^{-2} which is similar to that of the main bluegrasses. Many *Aristida* spp. are not strongly perennial, which means that they could be amenable to population manipulation by strategies such as controlled fire and crash grazing.

Notable absentees from the list in Table 2 are *B. pertusa*, *Alloteropsis semialata* (cockatoo grass) and *Melinis repens* (red Natal grass). *Alleloteropsis semialata* is a native species and is usually found on deep sandy soils in the region, some of which were sampled (Silcock *et al*. 2015). *Melinis repens* is very common on granite soils in speargrass pasture types and in ungrazed places such as roadsides, railway lines and cemeteries (FloraBase 2014). *Bothriochloa pertusa* is expanding its range into *Aristida/Bothriochloa* pastures but it would have been less common after the drought due to its poor tolerance of prolonged drought (McIvor 2007).

Table 2. Floristic summary for all 108 sites expressed as mean and maximum (max.) plant species frequency (%), plant density (m^{-2}) and percentage of the total pasture crown cover contributed by the main 100 species, plus groupings of them

Plant[A] type	Genus	Species	Site count	% of crown cover Mean	% of crown cover Max.	Plant density Mean	Plant density Max.	Frequency Mean	Frequency Max.
A1	*Bothriochloa*	*bladhii*	34	15.5	80.2	3.3	14.8	23.9	88
A1	*Bothriochloa*	*ewartiana*	25	24.5	61.6	3.1	12.0	30.5	68
A1	*Cenchrus*	*ciliaris*	32	18.5	94.8	3.5	20.2	21.0	100
A1	*Chrysopogon*	*fallax*	100	10.1	75.1	8.7	99.0*	30.7	96
A1	*Dichanthium*	*sericeum*	48	8.1	48.4	2.6	10.6	20.7	82
A1	*Enteropogon*	*acicularis*	25	2.6	12.2	0.6	1.8	6.0	22
A1	*Eremochloa*	*bimaculata*	40	12.3	56.1	11.7	44.9	29.6	76
A1	*Eulalia*	*aurea*	37	2.0	8.8	0.9	4.9	5.3	16
A1	*Heteropogon*	*contortus*	70	14.4	85.5	4.1	34.3	26.2	96
A1	*Themeda*	*triandra*	33	7.5	55.5	1.5	10.2	11.9	56
	Σ Key desirable perennial grasses		107	47.2	98.6	21.1	198.5	–	–
A2	*Aristida*	*armata*	20	3.2	31.5	0.8	8.6	9.8	72
A2	*Aristida*	*calycina*	69	4.2	23.2	1.0	5.1	13.5	46
A2	*Aristida*	*caput-medusae*	13	7.5	30.3	1.1	4.7	13.4	48
A2	*Aristida*	*holathera*	9	3.4	13.9	1.4	9.0	7.6	24
A2	*Aristida*	*jerichoensis*	55	7.7	42.7	1.4	5.2	16.9	54
A2	*Aristida*	*latifolia*	12	3.4	12.5	0.6	1.4	7.8	16
A2	*Aristida*	*leptopoda*	16	6.3	25.5	1.1	3.2	16.0	44
A2	*Aristida*	*personata*	14	8.0	42.8	2.1	8.4	21.5	66
A2	*Aristida*	*platychaeta*	11	5.1	12.3	2.1	5.3	17.6	40
A2	*Aristida*	*ramosa*	14	4.6	13.4	1.1	4.2	12.3	52
A	*Aristida*	sp.	26	2.3	11.2	0.5	2.5	7.4	24
	Σ A2 Aristidas		101	13.4	46.4	3.1	16.4	–	–
A2	*Bothriochloa*	*decipiens*	60	13.2	46.8	3.8	17.1	28.9	78
A2	*Chloris*	*divaricata*	49	4.2	25.9	2.2	13.1	17.0	72
A2	*Chloris*	*truncata*	9	1.7	5.3	0.6	1.5	4.9	12
A2	*Chloris*	*ventricosa*	19	1.5	6.1	0.6	1.8	6.4	18
A	*Chloris*	sp.	10	1.6	6.0	0.8	2.3	6.7	23
A2	*Cymbopogon*	*refractus*	49	4.1	30.2	0.6	3.4	8.3	48
A2	*Digitaria*	*ammophila*	8	1.4	5.6	0.4	1.4	6.3	16
A2	*Digitaria*	*brownii*	32	1.3	7.5	0.4	1.8	5.8	20
A2	*Digitaria*	*diffusa*	7	2.2	5.0	0.9	2.1	10.6	28
A2	*Digitaria*	*divaricatissima*	38	1.5	8.7	0.6	1.8	8.4	30
A2	*Digitaria*	*longiflora*	7	1.8	5.8	1.3	4.0	11.4	34
A	*Digitaria*	sp.	10	0.4	1.0	0.3	0.7	3.2	10
	Σ A2 Digitarias		63	2.2	10.9	0.9	4.1	–	–
A2	*Enneapogon*	*gracilis*	27	3.9	12.6	3.0	15.9	21.0	60
A2	*Enneapogon*	*intermedius*	7	1.6	4.2	1.7	3.3	14.6	36
A2	*Enneapogon*	*lindleyanus*	5	3.2	13.2	1.1	4.8	8.4	28
A2	*Enneapogon*	*pallidus*	10	1.3	3.8	0.5	2.1	7.3	26
A2	*Enneapogon*	*polyphyllus*	15	1.1	5.0	0.5	2.1	4.4	12
A2	*Enneapogon*	sp.	24	2.5	13.0	1.4	10.3	11.9	58
A2	*Enneapogon*	*virens*	6	1.1	4.6	0.6	1.7	6.7	16
	Σ A2 Enneapogons		74	3.1	20.3	2.0	16.1	–	–
A2	*Enteropogon*	*ramosus*	7	16.3	51.6	1.4	4.0	14.9	38
A2	*Eragrostis*	*brownii*	31	1.5	6.6	0.7	3.4	9.1	36
A2	*Eragrostis*	*cummingii*	5	3.7	8.9	1.1	2.4	14.4	24
A2	*Eragrostis*	*lacunaria*	46	2.5	16.2	1.4	21.2	10.9	80
A2	*Eragrostis*	*leptostachya*	10	1.4	4.6	0.4	0.9	5.4	10
A2	*Eragrostis*	*molybdea*	39	3.2	28.3	1.9	18.9	14.7	86
A2	*Eragrostis*	*sororia*	17	0.9	2.6	0.5	1.8	5.2	14
A	*Eragrostis*	sp.	11	0.8	2.0	0.3	0.6	4.5	8.0
	Σ A2 Eragrostis		85	4.0	29.3	2.2	23.6	–	–
A2	*Eriachne*	*mucronata*	11	6.4	26.3	0.8	3.4	10.7	46
A2	*Eriochloa*	*pseudoacrotricha*	35	2.8	15.5	1.2	4.9	10.3	38
A2	*Melinis*	*repens*	9	3.3	14.6	0.9	3.4	8.7	34
A2	*Panicum*	*buncei*	9	0.3	1.2	0.2	0.3	3.1	8.0
A2	*Panicum*	*decompositum*	9	0.8	2.1	0.2	0.6	3.2	4.9

(*continued next page*)

Table 2. (*continued*)

Plant[A] type	Genus	Species	Site count	% of crown cover Mean	% of crown cover Max.	Plant density Mean	Plant density Max.	Frequency Mean	Frequency Max.
A2	*Panicum*	*effusum*	65	1.4	6.1	0.5	2.6	7.7	30
A2	*Panicum*	*queenslandicum*	5	0.9	2.4	0.3	0.5	5.2	10
	Σ A2 Panicums		75	1.5	6.1	0.5	2.6	–	–
A2	*Paspalidium*	*caespitosum*	7	6.4	14.1	1.2	4.7	13.7	36
A2	*Paspalidium*	*constrictum*	15	2.2	22.6	0.6	3.5	6.0	36
A2	*Paspalidium*	*gracile*	5	1.1	3.0	0.7	2.0	2.8	4.0
A	*Paspalidium*	sp.	12	0.7	3.3	0.4	1.0	4.5	11.8
	Σ A2 Paspalidiums		26	3.5	22.6	0.9	6.2	–	–
A2	*Sporobolus*	*actinocladus*	5	2.9	6.2	0.9	3.0	7.5	17.5
A2	*Sporobolus*	*caroli*	17	1.8	6.1	0.7	2.0	9.9	26
A2	*Sporobolus*	*creber*	42	2.6	11.5	0.8	5.0	9.8	38
A2	*Sporobolus*	*elongatus*	17	3.3	17.0	0.9	3.4	10.8	38
	Σ A2 Sporobolus		50	3.2	17.0	1.0	5.0	–	–
A2	*Themeda*	*avenacea*	8	2.5	10.5	0.4	1.2	4.5	10
A2	*Tripogon*	*loliiformis*	62	5.2	53.6	7.5	50.6	22.9	88
A2	*Triraphis*	*mollis*	5	0.6	1.3	0.2	0.2	3.3	4.0
A2	*Urochloa*	sp.	5	1.2	3.9	0.7	1.5	6.3	9.7
A3	*Aristida*	*contorta*	21	4.4	18.2	1.4	5.4	13.9	48
A3	*Brachiaria*	*subquadripara*	6	11.7	34.5	11.5	23.1	34.7	74
A3	*Dactyloctenium*	*radulans*	10	1.6	7.5	0.7	1.6	7.5	20
A3	*Paspalidium*	*rarum*	5	1.1	2.8	1.6	7.6	8.5	34
A3	*Perotis*	*rara*	14	2.0	6.2	2.0	9.2	13.6	44
A3	*Setaria*	*surgens*	6	3.5	12.8	0.9	2.2	9.7	28
A3	*Sporobolus*	*australasicus*	11	2.2	11.0	2.0	7.0	12.0	30
A3	*Tragus*	*australianus*	42	2.6	22.6	2.6	19.4	14.8	72
	Σ A3 Annual grasses		70	6.2	38.9	4.4	24.2	–	–
Bf	*Cheilanthes*	*sieberi*	27	0.4	1.7	5.1	99*	11.3	44
Bs	*Cyperus*	*bifax*	10	0.7	1.9	2.5	10.9	9.4	36
Bs	*Cyperus*	*fulvus*	10	0.3	1.1	0.2	0.5	2.8	4.0
Bs	*Cyperus*	*gracilis*	35	0.8	4.7	1.4	15.0	7.4	44
Bs	*Cyperus*	*leiocaulon*	8	2.7	6.6	2.3	6.1	16.5	30
Bs	*Cyperus*	sp.	34	0.8	3.2	1.4	10.3	6.3	24
Bs	*Fimbristylis*	*dichotoma*	71	3.8	44.0	7.7	99*	23.3	94
Bs	*Fimbristylis*	sp.	14	1.1	4.9	1.4	8.9	5.9	26
	Σ Bs Small sedges		95	4.1	44.0	7.8	99*	–	–
Br	*Lomandra*	*leucocephala*	13	1.4	4.6	0.5	3.0	5.9	22
Br	*Lomandra*	*longifolia*	10	1.4	3.9	0.5	1.9	6.2	20
Ca	*Conyza*	sp.	10	0.7	2.2	1.9	8.0	9.3	26
Ca	*Helichrysum*	*ramosissimum*	19	0.4	2.5	1.6	7.6	12.1	50
Ca	*Vittadinia*	*sulcata*	10	0.2	0.3	0.3	0.8	3.0	6.0
	Σ Ca Daisies		54	1.1	16.0	1.9	19.0	–	–
Cc	*Salsola*	*kali*	10	0.7	3.7	0.7	4.8	4.6	20
Cc	*Sclerolaena*	*bicornis*	7	4.2	12.5	0.8	2.0	8.0	28
Cc	*Sclerolaena*	*birchii*	9	2.0	5.2	1.4	5.0	17.1	54
	Σ Cc Chenopods		22	3.3	16.1	1.9	8.0	–	–
Cl	*Desmodium*	sp.	6	0.1	0.2	0.1	0.2	2.4	4.0
Cl	*Glycine*	*tabacina*	47	0.3	1.6	0.8	4.6	14.1	54
Cl	*Glycine*	*tomentella*	23	0.7	2.7	1.0	8.4	10.5	56
Cl	*Indigofera*	*linifolia*	17	1.0	4.1	1.1	4.8	10.9	32
Cl	*Indigofera*	sp.	8	0.3	0.5	0.2	0.6	3.8	6.5
Cl	Native legume		5	0.1	0.3	0.2	0.3	5.2	8.0
Cl	*Neptunia*	*gracilis*	15	0.3	1.4	0.3	0.9	7.5	14
Cl	*Rhynchosia*	*minima*	19	0.1	0.3	0.2	0.7	3.8	10
Cl	*Zornia*	*muriculata*	12	0.3	0.9	0.2	0.8	3.0	8.0
	Σ Cl Herb legumes		72	0.7	5.3	1.3	8.7	–	–
Cm	*Malvastrum*	*americanum*	12	1.6	6.7	1.8	9.8	13.2	76
Cm	*Sida*	*corrugata*	23	0.4	1.5	0.5	1.8	6.2	26
Cm	*Sida*	sp.	29	1.5	8.7	1.6	7.0	17.6	46
	Σ Cm Malvaceae		64	1.2	8.9	1.4	10.0	–	–
Co	*Boerhavia*	*diffusa*	16	0.2	0.5	0.2	0.6	4.8	12

(*continued next page*)

Table 2. (*continued*)

Plant[A] type	Genus	Species	Site count	% of crown cover Mean	Max.	Plant density Mean	Max.	Frequency Mean	Max.
Co	*Brunoniella*	*australis*	64	0.6	6.5	1.4	8.8	15.7	68
Co	*Euphorbia*	*drummondii*	11	0.2	0.9	0.6	4.1	7.8	24
Co	*Evolvulus*	*alsinoides*	37	0.3	3.3	0.5	5.2	6.5	50
Co	*Oxalis*	*corniculata*	5	0.3	0.5	0.5	1.4	7.2	16
Co	*Phyllanthus*	*virgatus*	11	0.1	0.2	0.2	0.5	2.8	8.0
Co	*Rostellularia*	*adscendens*	18	0.3	1.0	0.4	2.5	4.6	20
Co	*Verbena*	*tenuisecta*	27	0.3	0.8	0.7	3.7	11.4	60
	Σ Co Other forbs		92	1.2	8.1	2.3	11.6	–	–
Cs	*Portulaca*	*oleracea*	15	0.2	0.4	0.3	0.5	4.3	8.0
Cs	*Portulaca*	sp.	12	0.4	1.3	0.4	1.2	5.7	14
Cs	*Trianthema*	*triquetra*	10	0.3	0.7	0.8	2.4	7.4	22
Cs	Cs Succulent forbs		32	0.3	1.4	0.6	2.9	–	–
	Σ All forbs		103	3.3	40.2	5.5	30.7	–	–

[A]Plant type is from QGraze where A1 = a key perennial grass, A2 = other perennial grass, A3 = annual grass, B = other monocotyledons plus ferns, C = dicotyledons. An asterisk means that all plants at a site were rated as diffuse members of a rhizomatous species.

There was at least one key perennial grass (A1 group) in all but one site and, on average, they provided 47% of the crown area of plants. In comparison, the annual grasses (A3 group) were found at only 70% of sites and averaged only 6.2% of the pasture crown area (Table 2). If floristic composition is judged by plant density, the same finding occurred – 21 A1 plants m^{-2} on average compared with 4.4 for the annual species.

Minor biomass species

Panicum species (panics) were commonly recorded but their contribution, other than that of *P. effusum*, was small – 1.5% of crown area and only 1 plant per 2 m^2 of pasture. *Enneapogon* spp. and *Eragrostis* spp. were more abundant than the panics but were still minor components of the diverse pastures (Table 2). Many of these are relatively preferred by livestock but they are weakly perennial or annual species, and their herbage mass is very variable and often low. *Tragus australianus* was the most common annual grass and *F. dichotoma* the most common small sedge. Chenopodiaceae and succulents were much less common than herbaceous Leguminosae (non- and potentially toxic) and the Malvaceae.

Some species had a high frequency at a limited number of sites, for example *Schizachyrium fragile* (fire grass), *Aristida mucronata* and *Fimbristylis bisumbellata* (average frequency >30%, but at fewer than five sites – absent from Table 2). Others had a low general frequency but occurred at many sites, for example *Cyperus gracilis* (slender sedge), *Digitaria divaricatissima* (umbrella grass), *Eulalia aurea* (silky browntop), *Evolvulus alsinoides* (tropical speedwell), *P. effusum*, *C. refractus* and *Sporobolus creber* (western rat's-tail) (all <10% average frequency and at >35 sites). *Cymbopogon refractus* was nominated by Tothill and Gillies (1992) as an abundant species when *Aristida/Bothriochloa* pastures are in good condition but, at 49 sites, it had an average density of only 1 plant per 1.7 m^2.

Cross-correlations of pasture variables

Generally the perennial plants with the greatest density and frequency (usually grasses) had the greatest live crown cover also, but not always, for example the forbs *B. australis*, *G. tabacina* and *Cyperus bifax* (downs nutgrass) were often prominent but had a low crown cover. Crown cover was not well correlated with plant density either. Species that had a relatively high plant density in comparison to their percent contribution to total crown cover were *F. dichotoma*, *C. fallax*, *T. loliiformis*, *E. bimaculata*, *Brachiaria subquadripara* (green summer grass) and *Cheilanthes sieberi* (mulga fern) (Table 2). In the case of *C. fallax*, *C. sieberi* and *E. bimaculata*, this is because their plants have short rhizomes and occur in diffuse swards, but this was not the case for *T. loliiformis* and *F. dichotoma*. Of these, all are perennials except *B. subquadripara*.

Frequency and plant density had higher correlations among the forb species (Table 2) and such correlations were also high for most perennial grasses. Species that did not conform to the general trend were *T. loliiformis*, *C. fallax* and *E. bimaculata* (Fig. 1). This is a useful correlation for routine surveys because frequency is relatively easily recorded. However, the lack of close correlation for the three major grasses mentioned means frequency data can underestimate pasture crown cover at sites where their tiller distribution is very diffuse. Species with a relatively high percentage of crown cover in relation to their plant density were *B. ewartiana*, *C. ciliaris*, *H. contortus*, *B. bladhii*, *Enteropogon ramosus* (twirly windmill grass) and *B. decipiens* (Fig. 2). Most of these are 3P grasses (palatable, productive, perennial grasses – Rolfe *et al*. 1997) although this is not the case for *E. ramosus* or *B. decipiens*. They all contribute significantly, however, to landscape stability and to available forage during dry seasons.

Relationships after aggregating minor species into groups

When species were in the 58 groups named in Appendix 1, the abundance order changed slightly with the second most abundant taxon becoming Aristida1 (branched seedhead, no awn column). These occurred at 91 sites (mean frequency >20% at 45 sites). An awn column forms in some *Aristida* spp. when the bases of the three awns twist tightly on themselves above

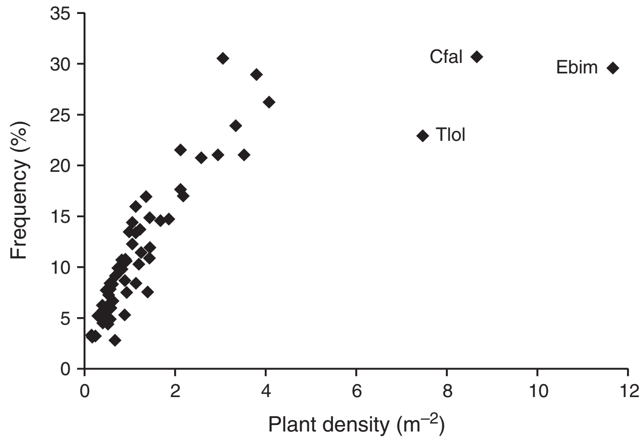

Fig. 1. Relationship between species frequency (%) and mean plant density (m^{-2}) for the perennial grass species growing in *Aristida/Bothriochloa* pastures in central Queensland. Cfal = *Chrysopogon fallax*, Ebim = *Eremochloa bimaculata*, Tlol = *Tripogon loliiformis*.

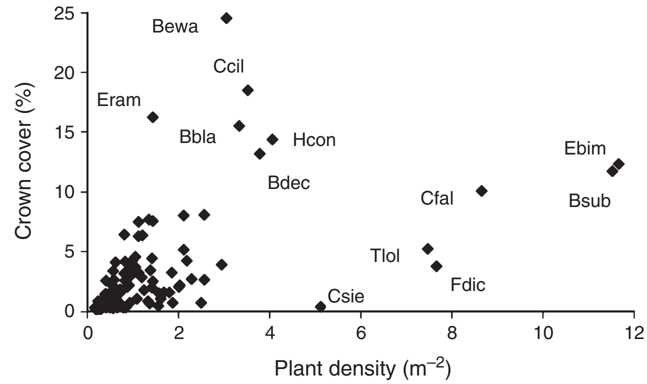

Fig. 2. Relationship between mean plant density (m^{-2}) and the mean percentage of the pasture crown area contributed by each of the 100 most common taxa recorded in *Aristida/Bothriochloa* pastures in central Queensland. Species codes: Bbla = *Bothriochloa bladhii*, Bdec = *Bothriochloa decipiens*, Bewa = *Bothriochloa ewartiana*, Bsub = *Brachiaria subquadripara*, Ccil = *Cenchus ciliaris*, Cfal = *Chrysopogon fallax*, Csie = *Cheilanthes sieberi*, Ebim = *Eremochloa bimaculata*, Eram = *Enteropogon ramosus*, Fdic = *Fimbristylis dichotoma*, Hcon = *Heteropogon contortus*, Tlol = *Tripogon loliiformis*.

the main seed, as in *A. latifolia* and *A. contorta*. We used four *Aristida* spp. groups (Appendix 1) when a known species could not be determined in the field. Other aggregated taxa, in descending order of abundance, were Cyperaceae (mean frequency 49% at 94 sites), *Enneapogon* spp. (22% at 74 sites), and the non-toxic Leguminosae (18% at 66 sites). These taxa are almost all found in the species lists of Tothill and Gillies (1992), except for the Cyperaceae and the non-grasses such as *B. australis*. At any site, there was at least one prominent guild (frequency >20%) and none had over 11 such prominent taxa during our surveys in relatively dry seasons.

Frequency versus crown cover

Though frequency is an easy recording method for describing the relative abundance of species in pasture, for many purposes the herbage mass or degree of cover provided to the ground are more important to landscape stability. Our data allows us to rank species for crown cover even though our estimation method was not as rigorous as that provided by a point frame or line intercept method (Whalley and Hardy 2000). The data show that, of the species that occurred at a large number of sites, *B. ewartiana* was the most abundant species in terms of crown cover where it occurred, followed by *C. ciliaris* and then *B. bladhii* (Table 3). The list in Table 3 is unsurprising because the plants therein are mostly large tussock perennial grasses. At some sites, particular species can be very dominant (>60% of pasture crown cover), such as *C. ciliaris* and *H. contortus* (Table 3), but all these species were absent at many *Aristida*/*Bothriochloa* pasture sites and in very small amounts at others.

Two species, sometimes with a high crown cover and which are not large plants, are *F. dichotoma* and *T. loliiformis*. Both are perennial and most common in open, heavily utilised pastures where they fulfil a very valuable role in restricting surface soil loss and overland flow.

Other species associations

For many common species or guilds, there was no biologically important correlation between their frequency and broad pasture health measures such as crown cover and plant density. Correlations of note are summarised in Tables 4 and 5. *Tripogon loliiformis*, a very small grass, was associated ($r = 0.69$) with high density swards, whereas Xanthorrhoeaceae (rushes and matrushes) ($r = -0.54$) and *C. ciliaris* ($r = -0.42$) were the opposite (Table 4). *Cenchus ciliaris* tends to occur as large individual plants whereas rushes are only common in open, heavily utilised pastures. Some strong correlations are more difficult to explain biologically, for example the moderately negative value ($r = -0.35$) between frequency and quadrat crown cover of Malvaceae.

The lack of a relationship between the frequency of *B. ewartiana* and other pasture variables at sites where it occurred (Table 4) was disappointing because it diminishes the usefulness of this important forage plant, which landowners can readily recognise, as an indicator species. Combining several variables, for example latitude, soil type and tree basal area, in a multiple regression analysis still only explained 32% ($P < 0.05$) of the factors associated with its abundance at a site and most of the variation was explained by latitude. This result reflects very well its known distribution in the area surveyed. Likewise, incorporation of multiple factors could only explain 39% of the recorded frequency of *D. sericeum* at a site, with soil type being the main factor and latitude a minor but significant one ($P < 0.05$). For most species, multiple regression analysis did not reveal any useful insights to their abundance that simple correlations had not detected.

The correlations in frequency of species pairs across sites were very variable. For many pairs, very few sites had both taxa present. For 18 pairs, however, there was a high degree of coexistence ($-0.60 \geq r \leq 0.60$) at moderate to high frequencies at a large number of sites (Table 5). Only one pair with a high correlation coefficient (*T. australianus* and *Enneapogon* spp., $r = 0.69$) was found at 30 sites (Table 5). Conversely, Cyperaceae and two of the *Aristida* spp. guilds were found to be very unlikely to coexist in many sites, based on our data ($r = -0.63$ and

Table 3. Range of crown cover recorded at individual sites for species that were abundant at many sites, expressed as a percentage of the total site pasture crown cover

Species	Number of sites	Mean (%)	Maximum (%)	Minimum (%)
Bothriochloa ewartiana	25	24.5	61.6	0.3
Cenchrus ciliaris	32	18.5	94.8	0.2
Bothriochloa bladhii	34	15.5	80.2	0.2
Heteropogon contortus	70	14.4	85.5	0.1
Bothriochloa decipiens	60	13.2	46.8	0.1
Eremochloa bimaculata	40	12.3	56.1	0.2
Chrysopogon fallax	100	10.1	75.1	0.1
Dichanthium sericeum	48	8.1	48.4	0.2
Aristida jerichoensis	55	7.7	42.7	0.3
Themeda triandra	32	7.5	30.3	0.1
Tripogon loliiformis	61	5.2	53.6	0.1
Chloris divaricata	46	4.2	25.9	0.1
Aristida calycina	69	4.2	23.2	0.1
Cymbopogon refractus	48	4.1	30.2	0.1
Fimbristylis dichotoma	69	3.8	44.0	0.1

Table 4. Correlations (>0.5) between plant guild frequency and three main quantitative pasture variables measured with a 0.25 m^2 quadrat, plus the same correlations for all major species and species groups (strong correlations are shown in bold)

Plant guild	Density	Projected cover	Crown cover	Site number involved
High correlations found				
Austrostipa spp.	–	–	–0.54	6
Brachiaria spp.	–	0.67	–	13
Other *Chloris* spp.	–	–	0.53	32
Enteropogon ramosus	–	0.52	–	7
Setaria spp.	–0.67	–	–0.59	9
Tripogon loliiformis	0.69	–	–	62
Xanthorrhoeaceae	–0.54	–	–	24
Major classificatory species				
Bothriochloa ewartiana	0.09	0.20	0.02	25
Brunoniella australis	0.14	0.04	0.22	65
Cenchrus ciliaris	**–0.42**	–0.09	0.13	32
Dichanthium sericeum	–0.03	0.27	–0.06	47
Eremochloa bimaculata	**0.44**	–0.02	0.11	40
Heteropogon contortus	0.04	0.29	0.20	70
Other guilds with high occurrence rates				
Aristida1	–0.04	–0.09	0.28	91
Aristida3	–0.24	0.08	0.24	59
Bothriochloa decipiens	0.26	0.22	**0.39**	60
Chrysopogon fallax	**0.31**	0.07	–0.09	100
Cyperaceae	**0.33**	0.19	–0.01	94
Enneapogon spp.	0.19	0.04	–0.23	74
Eragrostis spp.	0.25	–0.05	0.02	57
Malvaceae	0.04	–0.10	**–0.35**	64
Non-toxic Leguminosae	0.16	–0.07	0.18	65
Other forbs	–0.07	0.10	–0.18	86

–0.74). A high correlation between Queensland bluegrass and Aristida2 (clay soil wiregrasses, $r = 0.62$) was to be expected, as both prefer clay soils, and between succulents and *C. divaricata* ($r = 0.72$) as both are common species of scalded soil surfaces.

Other closely correlated pairings need further interpretation but should be noted carefully in future interpretive work on trends in pasture condition. For example, the high correlation ($r = 0.83$) of *Paspalidium* spp. (brigalow grasses) and *Eragrostis lacunaria* (purple lovegrass) was only for 17 sites, but at other sites, each species occurred separately at moderate frequencies (Table 2). Perhaps the high common co-occurrence of *T. triandra* and *B. ewartiana* ($r = 0.66$) might be used as an indicator of overgrazing at a site where grazing-sensitive *T. triandra* has a low frequency in the pasture compared with the more grazing-tolerant *B. ewartiana*.

Some commonly recorded species did not occur together very often, for example *C. ciliaris* and *E. bimaculata* occurred together at only three sites, whereas Sporobolus2 and desert bluegrass were found together at only one site. It seems unlikely that this lack of association is due to differences in grazing history of the pastures. More likely it is controlled by soil texture and its effect on soil moisture relations (*E. bimaculata* can be common on deep, white sandy soils where *C. ciliaris* is rare) or soil chemistry, such as high exchangeable aluminium levels to which *C. ciliaris* is sensitive (Spain and Andrew 1978) but our current state of knowledge limits further interpretation.

Lack of a high correlation in the presence (measured as plant frequency) of some main pasture taxa underscores the difficulty of defining *Aristida/Bothriochloa* pastures floristically. Notable examples are:

B. australis and *C. fallax* (co-existed at 56% of sites, $r = –0.12$),
B. decipiens and *C. fallax* (co-existed at 52% of sites, $r = –0.07$),
Aristida3 and Aristida1 (co-existed at 49% of sites, $r = –0.02$),
H. contortus and *E. bimaculata* (co-existed at 27% of sites, $r = –0.01$),
H. contortus and *C. ciliaris* (co-existed at 19% of sites, $r = –0.13$).

A healthy *H. contortus* pasture is not usually associated with abundant *C. ciliaris* or with an abundance of *E. bimaculata*. However, *C. fallax* is linked with declining pasture condition in *H. contortus* pastures (Wandera *et al*. 1993) and so too is *B. decipiens* in most pastures.

Differentiating pastures based on the dominant tree community

Although pattern analysis and ordination techniques failed to provide clear groupings among the sites based on our data, it was considered that there was a need to interpret our survey results in terms of the major eucalypt woodland types recognised by producers and regional community groups (Chilcott *et al*. 2005; FutureBeef 2014) as described earlier (Table 1). Even when one site, which was recorded as being naturally treeless, was omitted, there remained no major difference between them in broad pasture characteristics although poplar box generally had the highest mean value for pasture crown cover and projected ground cover, and narrow-leaved ironbark the lowest (Table 6). The lower values under the narrow-leaved ironbark/cypress pine (*Callitris glaucophylla*)/lemon-scented gum (*Corymbia citriodora*) group for pasture plant density and crown cover were associated with a higher average tree basal area. This lower

Table 5. Species or guilds with high levels of correlation (≥0.6) for co-existence at sites
n is the number of sites where the taxon was recorded, including where both occurred, *n* (pair)

Correln	Taxon 1 (t1)	Taxon 2 (t2)	*n* (pair)	*n* (t1)	*n* (t2)
0.83	*Paspalidium* spp.	*Eragrostis lacunaria*	17	33	46
0.82	*Eulalia aurea*	Aristida4	10	37	29
–0.74	Cyperaceae	Aristida2	16	94	17
0.72	Succulents	*Chloris divaricata*	19	29	48
0.69	*Tragus australianus*	*Enneapogon* spp.	35	42	74
0.69	*Panicum effusum*	Other annual grasses	17	63	31
0.69	*Panicum effusum*	*Bothriochloa ewartiana*	14	63	25
0.69	*Chrysopogon fallax*	*Brachiaria* spp.	13	100	13
0.68	Sporobolus1	Non-toxic Leguminosae	15	28	36
0.67	*Tragus australianus*	Aristida3	10	42	29
0.66	*Themeda triandra*	*Bothriochloa ewartiana*	11	33	25
0.65	*Panicum* spp.	Aristida2	10	26	17
0.63	*Tripogon loliiformis*	Chenopodiaceae	18	62	23
0.63	*Panicum* spp.	Asteraceae	15	26	52
–0.63	Cyperaceae	*Aristida latifolia*	10	94	12
0.62	*Dichanthium sericeum*	Aristida2	16	47	17
0.61	*Digitaria* spp.	*Digitaria divaricatissima*	13	30	32
0.60	*Panicum effusum*	Pteridophyta	15	63	26

Table 6. Mean pasture variables when grouped by the three main tree overstorey species (Narrow-leaved ironbark, NL I/bark; Silver-leaved ironbark, SL I/bark; and Poplar box, Pop box)
*$P < 0.05$; n.s., not significant

	Vegetation type				
	NL I/bark	SL I/bark	Pop Box	Mean	Level of significance
Number of sites	26	30	51		
Plant density (m^{-2})	43.1	46.3	52.8	48.6	*
Projected pasture cover (rating from 0 to 6)	4.0	3.9	4.2	4.1	n.s.
Pasture crown cover (%)	1.2	1.6	1.8	1.6	n.s.
Tree basal area ($m^2 ha^{-1}$)	7.5	4.5	5.7	5.8	*

pasture density is probably related also to a lower inherent soil fertility and water-holding capacity of sandy-textured soils (McKenzie *et al*. 2000).

The number of plant guilds recorded at any site ranged from a minimum of six at one narrow-leaved ironbark site to a maximum of 33 at one poplar box site. The average number of guilds for each tree overstorey type was 20, 19 and 22 for narrow-leaved ironbark, silver-leaved ironbark and poplar box sites, respectively. The narrow-leaved ironbark and silver-leaved ironbark sites had a similar distribution of numbers of taxa either side of the mean, whereas the poplar box community had a higher proportion of sites with >22 taxon groups.

If a frequency of 20% is an indicator of a prominent species, there were fewest such pasture species in the narrow-leaved ironbark community (60% of sites recorded less than five prominent species), intermediate numbers in the silver-leaved community (80% of sites recorded between three and eight prominent species) and the highest number in the poplar box community (60% of sites recorded between six and eleven prominent species). Presumably a larger number of prominent species should buffer those pastures better against biological disasters, such as pests, diseases, unseasonal climatic extremes, and poor grazing management.

Floristic differences related to the dominant tree

Table 7 details the percentage of sites at which each of the 58 plant guilds occurred in each of the three identified woodland types. Eight species or guilds occurred consistently at half or more of all sites in each tree overstorey group. They were *C. fallax*, Aristida1, *Enneapogon* spp., *P. effusum*, non-toxic Leguminosae, *B. australis*, Cyperaceae and other forbs. There were few species with a markedly different frequency of occurrence among the tree types, most notably *B. ewartiana* (range, 4–48%), *D. sericeum* (range, 15–61%) and *C. divaricata* (range, 4–73%) (Table 7).

The main pasture taxa distinguishing these tree communities by their abundance were:

- narrow-leaved ironbark – presence of *E. bimaculata* and Aristida4; absence of Aristida2,
- silver-leaved ironbark – presence of potentially toxic Leguminosae, and
- poplar box – presence of *C. divaricata*.

These differentiating taxa partly match those that Weston *et al.* (1981) suggested for sub-groups mapped by them in central Queensland, namely *Eragrostis* spp., *Chloris* spp. and *Aristida* spp. *Bothriochloa ewartiana* is a typical silver-leaved ironbark

Table 7. Proportion (%) of sites within the three main tree groups (Narrow-leaved ironbark, NL I/bark; Silver-leaved ironbark, SL I/bark; and Poplar box, Pop box) where members of the 58 derived herbaceous guilds were recorded
Interpretation of plant guild code is given in Appendix 1

Plant type	Taxon or guild	Overstorey tree community		
		NL I/bark $n=26$	SL I/bark $n=30$	Pop box $n=51$
Perennial grasses				
Key grasses	*Astrebla* spp.	0	3	6
	Bothriochloa bladhii	8	35	41
	Bothriochloa ewartiana	4	48	18
	Cenchrus ciliaris	27	19	37
	Chrysopogon fallax	92	90	94
	Dichanthium sericeum	15	61	49
	Eremochloa bimaculata	65	29	27
	Eriochloa spp.	27	29	37
	Heteropogon contortus	65	90	49
	Themeda triandra	15	45	29
	Urochloa spp.	4	10	8
Other grasses	Aristida1	100	74	82
	Aristida2	0	23	22
	Aristida3	58	48	59
	Aristida4	54	13	22
	Aristida latifolia	0	16	14
	Austrostipa spp.	4	0	10
	Bothriochloa decipiens	42	45	69
	Bothriochloa pertusa	0	6	0
	Chloris divaricata	4	32	73
	Other *Chloris* spp.	23	26	35
	Cymbopogon spp.	69	32	41
	Cynodon spp.	0	0	4
	Digitaria brownii	38	16	33
	Digitaria divaricatissima	35	19	45
	Other *Digitaria* spp.	50	13	25
	Enneapogon spp.	54	74	73
	Enteropogon acicularis	19	6	37
	Enteropogon ramosus	4	0	12
	Eragrostis lacunaria	46	26	51
	Eragrostis molybdea	19	32	47
	Other *Eragrostis* spp.	73	45	47
	Eriachne spp.	19	13	14
	Eulalia aurea	19	29	45
	Melinis repens	0	16	8
	Panicum effusum	62	65	55
	Other *Panicum* spp.	4	23	35
	Paspalidium spp.	35	26	31
	Setaria spp.	35	0	0
	Sporobolus1	0	26	39
	Sporobolus2	58	29	51
	Tripogon loliiformis	38	42	76
	Other perennial grasses	58	39	16
Annual grasses				
	Brachiaria spp.	31	0	10
	Tragus australianus	27	52	37
	Other annual grasses	54	39	10
Sedges, lilies and ferns				
	Cyperaceae	88	77	92
	Liliaceae	8	3	0
	Pteridophyta	35	6	29
	Xanthorrhoeaceae	46	19	12
Dicotyledon forbs				
	Asteraceae	58	45	47
	Brunoniella australis	50	65	63

(*continued next page*)

Table 7. (*continued*)

Plant type	Taxon or guild	Overstorey tree community NL I/bark $n=26$	SL I/bark $n=30$	Pop box $n=51$
	Chenopodiaceae	8	13	33
	Malvaceae	46	55	69
	Non-toxic Leguminosae	54	81	53
	Potentially toxic Leguminosae	15	61	27
	Succulents	4	26	39
	Other forbs	85	68	86
Taxa at ≥50% of sites	–	19	13	15

Table 8. Average frequency (%) of plant guilds that were present at 50% or more of sites within each tree overstorey group
Guilds below the dotted line only comply within one overstorey tree group

Narrow-leaved ironbark	Average frequency	Silver-leaved ironbark	Average frequency	Poplar box	Average frequency
Chrysopogon fallax	28	*Chrysopogon fallax*	23	*Chrysopogon fallax*	36
Cyperaceae	35	Cyperaceae	17	Cyperaceae	26
Aristida1	28	Aristida1	21	Aristida1	23
Other forbs	15	Other forbs	19	Other forbs	18
Enneapogon spp.	15	*Enneapogon* spp.	15	*Enneapogon* spp.	18
Non-toxic Leguminosae	18	Non-toxic Leguminosae	13	Non-toxic Leguminosae	12
Brunoniella australis	7	*Brunoniella australis*	14	*Brunoniella australis*	19
Panicum effusum	9	*Panicum effusum*	7	*Panicum effusum*	7
Heteropogon contortus	28	*Heteropogon contortus*	32	–	–
	–	*Dichanthium sericeum*	18	*Dichanthium sericeum*	25
	–	Malvaceae	11	Malvaceae	17
Aristida3	18	–	–	Aristida3	11
Eremochloa bimaculata	27	–	–	–	–
Other annual grasses	21	–	–	–	–
Aristida4	16	–	–	–	–
Daisies	14	–	–	–	–
Other *Digitaria* species	13	–	–	–	–
Other *Eragrostis* spp.	11	–	–	–	–
	–	*Tragus australianus*	15	–	–
	–	Potentially toxic Leguminosae	13	–	–
	–	–	–	*Bothriochloa decipiens*	33
	–	–	–	*Tripogon loliiformis*	30
	–	–	–	*Chloris divaricata*	18
	–	–	–	Sporobolus2	14
	–	–	–	*Eragrostis lacunaria*	11

country species but, in this analysis, its occurrence at 48% of such sites was just less than the defined 50% needed for inclusion.

An 'average' composition for *Aristida/Bothriochloa* pastures is probably derived by considering only those pasture guilds that occurred at more than 50% of a tree group's sites. Table 8 has been created using that criterion. The taxa listed in the top half of the table are common to two or three of the tree overstorey types, whereas those below the dotted line are common in only one. In practice, the 'Other forbs' group of 59 taxa has no diagnostic value but does highlight the presence of a diverse group of non-grasses in these pastures, in varying profusion, and that does not include the very common Asteraceae guild (Table 7).

Indicator species

Frequency of common species, such as *B. decipiens*, Cyperaceae spp. and *C. fallax*, was generally not strongly correlated with projected soil surface cover, crown cover or plant density whereas it was for less common species, such as other *Chloris* spp. guild ($r=0.53$) and *Setaria* spp. (pigeon grasses) ($r=-0.67$) (Table 4). Presumably, the consistent, but sometimes small, presence of important forage species at many sites diminished the chance of high cover correlations (above ± 0.5) and thus their absence from Table 4. *Chrysopogon fallax* is thought to be too common and resilient under grazing to have value as a grazing pressure indicator in this community, whereas the Aristida1 guild seems more suitable and sensitive to management in our experience. Preferred, short-lived perennials have intuitive appeal as indicator species, for example *P. effusum* and *Enneapogon* spp., but their abundance will also reflect recent droughts or fires that temporarily denude landscapes. The correlations between species abundance and pasture condition rating and soil type, are examined in Silcock *et al*. (2015).

Typical pasture composition

Pasture managers would like to have a description for *Aristida/Bothriochloa* pasture in different condition states. Hall *et al*. (1994) made a preliminary attempt using visual field experience but it was primarily based on tree and shrub density and soil erosion. Other publications relevant to central Queensland are often for a single locality (Shaw and 't Mannetje 1970; McIntyre and Lavoral 2001; Orr *et al*. 2001) and some only name broad species groups (Wandera *et al*. 1993). Fairfax and Fensham (2000) covered many sites in detail but the data are not presented in a way that most landholders could use directly in their property management.

When we examined the 19 sets of the survey data from adjacent locations that were in different apparent condition due to land management, we found little evidence that the floristic composition of the pastures was markedly different. The differences were most obvious for pasture crown cover and soil parameters that are discussed in Silcock *et al*. (2015). Table 8 is our nearest approximation to a broad quantified description of the floristic composition of *Aristida/Bothriochloa* pasture. As a preliminary benchmark, an *Aristida/Bothriochloa* pasture in fair or B condition would likely have the following frequencies recorded for these four common species – *C. fallax* 30%, Aristida1 25%, *Enneapogon* spp. 15% and *P. effusum* 8%. A few other perennial species would have a frequency of 10–20% at particular sites but sites with that frequency for those other species would be restricted in number. There would be 10–20 other species with 1–10% frequency at most sites. These would rarely be a significant component of the herbage mass yet could assume transient prominence in certain years when seasonal conditions favour them. It would also be normal to find, at a particular site in a given year, one or two sedge or legume species with a high frequency of occurrence (30–40%) but with a very low herbage mass (<5% of the pasture) as Shaw and 't Mannetje (1970) reported for black speargrass pasture.

If the measure of species abundance was crown cover, the picture is no clearer and might involve a maximum of 20% of the total for one or two grasses (say *B. ewartiana* or *B. decipiens*) followed by a steadily decreasing proportion of five other grasses, such as *D. sericeum*, *C. divaricata*, *C. fallax* and *T. loliiformis*, contributing 5–12% of the total pasture crown cover each. There would be about 10 other grass species contributing 1–5% to the crown cover and finally many minor species, mostly taprooted forbs, each contributing less than 1% to the total pasture crown cover.

Those lists need to be combined with projected ground cover and woody plant density to arrive at a comprehensive rating of pasture condition. More needs to be done via programs, such as QGraze, to refine the current science into practical packages such as Roberts (1972) attempted in the 1970s for western Queensland and Scanlan *et al*. (2014) have recently offered using computer modelling. In the latter case, the definition of a perennial grass is critical and many common ones in this region that are not truly annuals do not readily conform to the notion of a long-lived plant that is almost certainly alive to regrow once summer rains fall, for example many *Aristida*, *Enneapogon*, *Eragrostis* and *Chloris* species. However, our new lists of prominent taxa are a big advance on the tentative lists offered by Tothill and Gillies (1992) and Hall *et al*. (1994).

Since our survey, native pasture condition in northern Australian rangelands has been set into four broad categories (A, B, C and D) (Chilcott *et al*. 2005; Hunt *et al*. 2014) compared with the three (with sub-groups) used in our survey. Essentially our B– and C+ categories have been amalgamated into those pastures that are still healthy enough to rejuvenate via persistent good grazing management (C class) whereas our C and C– categories are those that can only be rejuvenated via significant inputs of machinery and other resources (D condition).

Practical considerations

Most pasture managers have difficulty in identifying the many individual *Aristida* species in the field. It is a large genus and is sub-divided into several taxonomic sections but the distinguishing features of each require microscopic examination and considerable experience in the use of taxonomic keys (Simon and Alfonso 2014). The discriminating features, suggested by McIntyre and Filet (1997) to create sub-groups, are not an adequate field solution because magnification is still required. Seed-head shape, diaspore size, twisted column presence, dead leaf curliness and leaf width seem to offer the best discriminating field characteristics for local wiregrasses.

Differentiating the bluegrasses (*Bothriochloa* and *Dichanthium* spp.) is also challenging for many novice pasture managers but less so than the *Aristida* spp. Other common grasses, such as *C. refractus*, *E. aurea* and *T. australianus*, are, by comparison, much easier to identify and thus potentially useful in floristic descriptions of *Aristida/Bothriochloa* pastures. We are not confident that our identification to species level in the field was always accurate. However, if our acknowledged level of expertise is inadequate, landholders and pastoralists have little chance of assessing their *Aristida/Bothriochloa* pastures objectively based on species composition.

Conclusions

The *Aristida/Bothriochloa* pastures, as constituted by Weston *et al*. (1981) and Tothill and Gillies (1992), remain a floristically diverse and difficult type to group for the purposes of property management. The most common species across all 108 sites was *C. fallax* followed by a group of other perennial grasses with a lower frequency of occurrence, both within and among sites. Their comparative ranking varied with the variable used and consisted chiefly of *A. calycina*, *H. contortus*, *B. decipiens* and *T. loliiformis*.

Live crown cover and total projected ground cover bore an inconsistent relationship to plant frequency and plant density because growth habits and plant type were so diverse. Hence single pasture abundance parameters cannot provide a very informed interpretation of the condition of *Aristida/Bothriochloa* pasture. Further research is needed into the reaction of key pasture species to grazing management, climatic extremes, woody plant density, competition and fire (Scanlan *et al*. 2014) so that the diverse floristic composition can be better controlled or predictably modified when required.

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Appendix 1. The 58 derived plant groups or guilds from the survey and their constituent taxa

The plant types are derived from the main categories in QGraze and the pasture plant groups are the 58 guilds based on the expert knowledge of the authors

Plant type	Pasture plant group	Members of group
A3	Other annual grasses	13 species apart from any ones named herein, for example *Perotis rara*, *Dactyloctenium radulans*, *Schizachyrium* spp.
A2	Aristida1 – branched seedheads, no awn column	8 species including *Aristida armata*, *Aristida calycina*, *Aristida jerichoensis* and *Aristida lazaridis*
A2	Aristida2 – from clay soils, no awn column	*Aristida leptopoda* and *Aristida platychaeta*
A2	Aristida3 – unbranched seedheads, no awn column	10 species including *Aristida ramosa*, *Aristida caput-medusae*, *Aristida gracilipes* and *Aristida schultzii*
A2/A3	Aristida4 – long, twisted awn column	*Aristida contorta* and *Aristida holathera*
A2	Feathertop wiregrass	*Aristida latifolia*
A1	Mitchell grasses	*Astrebla elymoides* and *Astrebla lappacea*
A2	Corkscrew grasses	*Austrostipa scabra* and *Austrostipa verticillata*
A1	Forest bluegrass	*Bothriochloa bladhii*
A2	Pitted bluegrass	*Bothriochloa decipiens*
A1	Desert bluegrass	*Bothriochloa ewartiana*
A2	Indian couch	*Bothriochloa pertusa*
A3	*Brachiaria* species	*Brachiaria* spp. (3 taxa)
A1	Buffel grass	*Cenchrus ciliaris*
A2	Slender windmill grass	*Chloris divaricata*
A2/A3	Other *Chloris* species	Other *Chloris* spp. (4 taxa)
A1	Golden beard grass	*Chrysopogon fallax*
A2	*Cymbopogon* species	*Cymbopogon* spp. (2 species)
A2	Couch grasses	*Cynodon* spp. (2 species)
A1	Queensland bluegrass	*Dichanthium sericeum*
A2	Cotton panic	*Digitaria brownii* (2 taxa)
A2	Umbrella grass	*Digitaria divaricatissima*
A2	Other *Digitaria* species	*Digitaria* spp. (6 other taxa)
A2/A3	Bottlewasher grasses	*Enneapogon* spp. (9 taxa)
A2	Curly windmill grass	*Enteropogon acicularis* (2 taxa)
A2	Twirly windmill grass	*Enteropogon ramosus*
A2	Purple lovegrass	*Eragrostis lacunaria*
A2	Granite lovegrass	*Eragrostis molybdea*
A2/A3	Other lovegrasses	*Eragrostis* spp. (8 taxa)
A2	Poverty grass	*Eremochloa bimaculata*
A2/A3	Wanderrie grasses	*Eriachne* spp. (2 taxa)
A2	Spring grasses	*Eriochloa* spp. (3 taxa)
A2	Silky browntop	*Eulalia aurea*
A1	Black speargrass	*Heteropogon contortus*
A2	Red Natal grass	*Melinis repens*
A2	Hairy panic	*Panicum effusum*
A2	Other panics	*Panicum* spp. (7 taxa)
A2	Brigalow grasses	*Paspalidium* spp. (7 taxa)
A2	Other perennial grasses	Poaceae (20 minor perennial grasses, incl. *Triodia* spp.)
A2/A3	Pigeon grasses	*Setaria* spp. (1 species)
A2/A3	Sporobolus1 – branched seedheads	*Sporobolus actinocladus*, *S. australasicus* and *S. caroli*
A2	Sporobolus2 – rat's-tail grasses	*Sporobolus creber* and *S. elongatus*
A1	Kangaroo grass	*Themeda triandra*
A3	Small burrgrass	*Tragus australianus*
A2	Five-minute grass	*Tripogon loliiformis*
A1/A2/A3	*Urochloa* species	*Urochloa* spp. (3 taxa)
Bs	Small sedges	Cyperaceae (13 taxa)
Bl	Lilies	Liliaceae (1 taxon)
Br	Rushes and matrushes	Xanthorrhoeaceae (8 taxa)
Bf	Ferns	Pteridophyta (2 taxa)
Co	Blue trumpet	*Brunoniella australis*
Ca	Daisies	21 Asteraceae, annual and perennial, including *Calotis lappulacea*
Cl	Potentially toxic Leguminosae	6 taxa, including *Crotalaria* spp., *Indigofera* spp. and *Swainsona* spp.
Cl	Non-toxic Leguminosae	15 taxa, including *Glycine* spp., *Rhynchosia minima*, *Desmodium* spp. and *Cullen* spp.
Cc	Chenopods	11 species of Chenopodiaceae including *Sclerolaena* spp.

(*continued next page*)

Appendix 1. (*continued*)

Plant type	Pasture plant group	Members of group
Cm	Flannel weeds and relatives	15 taxa, including Malvaceae and *Sida* spp.
Cs	Succulents	Portulacaceae, Aizoaceae (7 taxa)
Co	Other forbs	59 other forb species, annuals and perennials, from 20 families