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Vegetation trend in the east Kimberley region : an analysis of ground monitoring data from 1991-1998

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DEVELOPMENT OF INFORMATION PRODUCTS FOR REPORTING RANGELAND CHANGES

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1. Introduction

1.1 Report outline

This document summarises the analyses carried out on the ground monitoring data from the Kimberley region of Western Australia as part of the Natural Heritage Trust project 953024 - ‘'Development of Information Products for Reporting Rangeland Changes.”

This project has been investigating ways of integrating rangeland trend information collated from Landsat satellite data and site-specific ground vegetation data. This has been carried out by extending and refining previous approaches developed by Agriculture Western Australia and CSIRO Mathematical and Information Sciences (*e.g.* Wallace *et al.* 1994). The principal objective of the project is to develop useful information products which can be used for the reporting of changes in rangeland ecosystems.

As it is not sensible, nor even possible, to carry out the development of such a system over the entire Western Australian rangelands, studies have concentrated on the savanna grasslands of northern Australia. This area was selected as it encompasses a large proportion of Australia’s rangelands (1 million km^2 or approx. 15%) and because it is a focus of sustainability research through the CRC for the Sustainable Development of Tropical Savannas.

Three specific test areas were identified for further study: east of Halls Creek in the East Kimberley; around Fitzroy Crossing in the West Kimberley; and adjacent to Karratha in the Pilbara region. These particular areas were selected after considering the availability of historic (pre-1994) and current quantitative vegetation monitoring data, Landsat satellite image boundaries and the wish to encompass both the Kimberley and Pilbara grasslands. It also allowed linkages with similar projects (e.g. Department of Lands, Planning and Environment’s monitoring work in the Victoria Rivers District of the Northern Territory) and with interested parties (*e.g.* Hamersley Iron Pty Ltd).

This study reports on the vegetation trends that have been assessed in the first of the study areas identified above, the Halls Creek region, using ground monitoring data collected from 1991-1997. Additional reassessment data (1995/96 and 1998) were also available for an area to the north west of this study area and this has been included for comparative purposes (this area is referred to as the Mt Ramsey/Dixon Range area). Note that vegetation trends have been assessed from two perspectives (a) pastoral purposes, using changes in the frequency of desirable and undesirable species/groups of species, and (b) landscape function, using changes in total frequency of perennial plants. Changes in woody shrub and tree cover have also been examined.

1.2 Study region

The Halls Creek study area is located to the east of Halls Creek in the eastern Kimberley region of Western Australia. The area is roughly encompassed by Landsat scene 106/73 (Figure 1) and includes four pastoral leases.

Climatically, the study area can be described as ‘dry tropics’, with a warm dry climate that is characterised by a 4-5 month rainy season (usually November to March). Although most of the area receives around 400-500 mm of rainfall annually, the amount can vary greatly (records show yearly totals of more than 800 mm; Slatyer 1970). The mean average yearly rainfall for Halls Creek is 526 mm, with a November to March average of 461 mm. Maximum temperatures average more than 32°C between September and April (Bureau of Meteorology 1999).

The area is geologically and geomorphologically variable. It has been divided into a number of geomorphological units including elevated plains, erosional plains, simple fold mountains and structural plateaux. The soils of the study area include alluvial cracking clays, basalt derived cracking clays, loamy and sandy red earths, and skeletal soils (Paterson 1970; Stewart 1970; Traves et al. 1970).

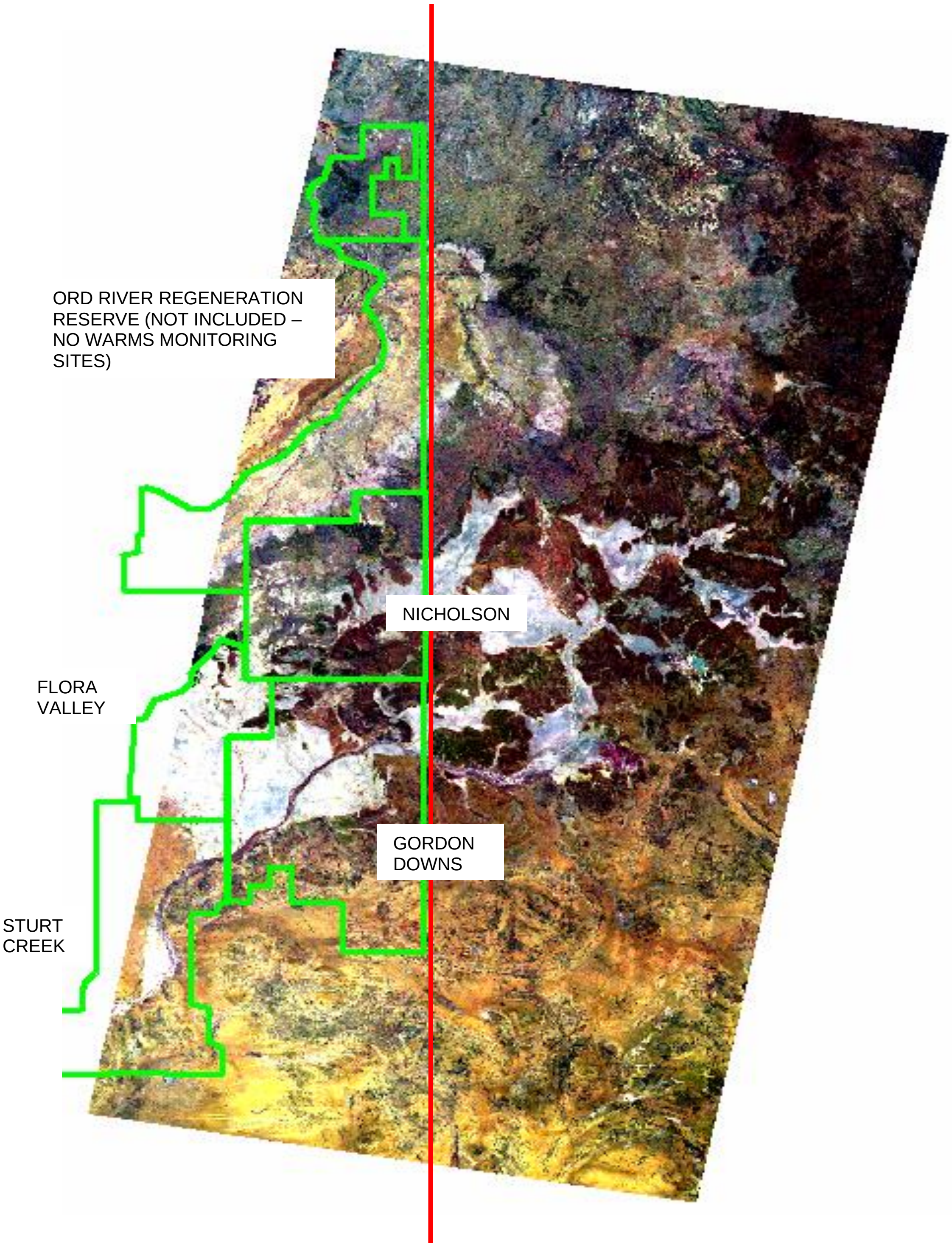


Figure 1: 'Halls Creek' LANDSAT scene 106/73 overlain with approximate pastoral lease boundaries (green) and the Western Australia/Northern Territory border (red). Landsat scene is approximately 180 x 360 km.

The vegetation within the region is typically woodlands with grassy understoreys, although on the cracking clay plains trees may be sparse or absent (Perry 1970). Major vegetation types include the black soil (Mitchell grass - *Astrebla* spp.) communities, which dominate on cracking clay plains; soft spinifex (*Triodia pungens*) communities which are present on red soils; and Hard Spinifex (*Triodia wiseana*) communities which predominate in more arid habitats. Further details of the vegetation and pasture types in the region can be obtained from Perry (1970a), Perry (1970b) and Tothill and Gillies (1992).

1.3 Description of the ground data

1.3.1 Site and vegetation type information

Halls Creek region

This study concentrated on monitoring data collected from the four pastoral stations which fall directly within the Halls Creek study area (total lease area of approximately 11400 km^2). These stations are Flora Valley (21 monitoring sites), Gordon Downs (12 sites), Sturt Creek (8 sites) and Nicholson (8 sites; Figure 2). Much of the data were collected as part of the current WARMS program, although the number of sites per station is higher than for WARMS. Some older data dating back to 1991 were also available. Forty seven monitoring sites in the region have been revisited at least once (Table 1). The sites were stratified into two main vegetation types, black soil plains (Mitchell grass) and soft spinifex (for description of these types see Duckett 1997). The remaining site was classified as frontage grass (on the basis of species composition) although it is found on the red soil Geebee landsystem. Note that WARMS sites are stratified across a region by vegetation type, fragility and productivity. They are located according to distance from water, representativeness of the vegetation community within each paddock or grazed areas, and for ease of access.

Table 1: Classification of vegetation at reassessed monitoring sites within the Halls Creek study region. Further details of each vegetation type are given in Duckett (1997).

Pasture community	Soil type	Number of reassessed sites
Black soils (Mitchell grass)	Cracking clay	35
Soft spinifex	Red/yellow earths with laterite	11
Frontage grass?	Alluvial floodplain	1
Total		**47**

Data from the study area were available for a number of overlapping periods. To reduce the complexity of the interpretation only two times, 1991-1994 and 1994-1997, were examined. Analysis of the soft spinifex sites was only possible for the second assessment period as sites were only installed in 1994.

Mt Ramsey/Dixon Range area

The data from this area were collected as part of the 1995/96-1998 East Kimberley WARMS assessments. Separate analyses were undertaken for this data and results have been tabulated separately to the data from the Hall Creek study area. The Mt Ramsey/Dixon Range dataset includes data for 26 reassessed sites which have been classified into 4 vegetation types (Table 2). These sites are located on the following pastoral leases – Alice Downs, Bedford Downs, Bow River, Lansdowne, Mabel Downs, Margaret River, Moola Bulla, Mt Amhurst and Springvale.

Table 2: Classification of vegetation at monitoring sites for the 1995/96-1998 Mt Ramsey/Dixon Range reassessments in the East Kimberley. Further details of each vegetation type are given in Duckett (1997).

Pasture community	Soil type	Number of reassessed sites
Limestone grass	Skeletal soils	12
Black soil plains (Mitchell grass)	Cracking clay soils	6
Southern ribbongrass	Red brown, red and yellow earths	7
Curly spinifex/ribbongrass	Red and yellow sandy soils	1
Total		**26**

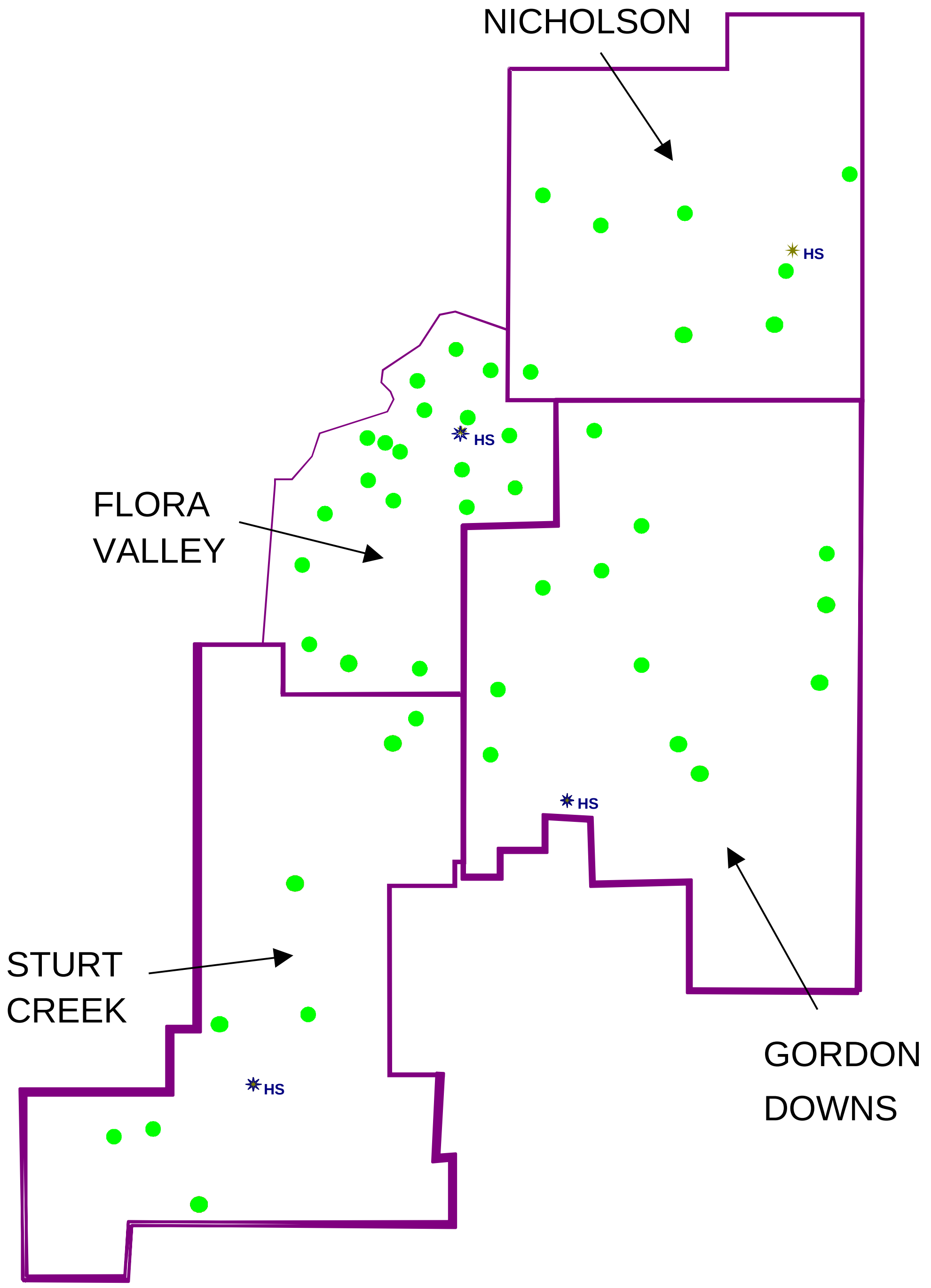


Figure 2: Distribution of ground monitoring sites on the four pastoral properties within the Halls Creek study area (HS=homestead).

It should be noted that information from a much larger dataset was used in preliminary analyses to stratify sites in vegetation types. This additional dataset included data for over 100 sites located east of Halls Creek and in the adjacent Victoria River District of the Northern Territory. These data have been collected by Agriculture Western Australia (AGWEST) as part of the WARMS program; for fire studies conducted by Andrew Craig, AGWEST Kununurra; and also by the Northern Territory Department of Lands, Planning and Environment for their monitoring program.

1.3.2 Vegetation data

Two major types of vegetation information have been collected at the monitoring sites and analysed. Firstly, percentage frequency of occurrence estimates were collected for all perennial and important annual species. Estimates were generally made using 100 (0.7 m by 0.7 m) semi-permanent quadrats placed approximately 2.5 m apart along 5 marked transects, although at a small number of sites frequency was recorded from 1.0 m^2 quadrats. Secondly, percentage crown cover of shrubs and trees over 1 m in height was estimated using a Bitterlich gauge. Crown cover for each site was calculated as an average of estimates made at the beginning and end of transects 1, 3 and 5, *i.e.* six in total. Details of all procedures are given in the WARMS manual (Strutt *et al.* 1995).

1.4 Analysis methodology

1.4.1 Different analysis perspectives

Traditionally, rangelands have been assessed by Agriculture Western Australia from the perspective of whether or not the species present are those desirable for pastoral land use. However, there is emerging support for the view that the priority for ecosystem management must be the preservation of the productive potential of ecosystems. A well functioning landscape has numerous patches associated with perennial grasses, shrubs or trees which trap the rainfall or surface water, and retain the litter that would otherwise be washed or blown away. In a functional ecosystem there is close coupling between the rainfall, nutrients and energy trapped by the ecosystem and productivity, and the conversion of these resources into biomass is maximised. A fully functional system can potentially support the full expression of biodiversity and provides opportunities for a range of end users. Loss of these perennial plants and their associated resource-capturing patches, leads to landscape dysfunction. This may change the ability of the landscape to meet the requirements of land users.

Monitoring rangeland landscapes should, therefore, be based on the assessment of change in resource-capturing patches, through direct or indirect measures, and the frequency, dynamics and proportion of perennial species that influence the productivity or services of the landscape for the end user. Taking this into account, vegetation trends in the Halls Creek study area have been assessed from two perspectives (a) pastoral purposes, using changes in the frequency of desirable and undesirable species/groups of species, and (b) landscape function, using changes in total frequency of perennial plants.

1.4.2 Analysis techniques

Two techniques for analysing the frequency data have been used in this study, frequency plots and ordination analyses. These techniques have been described in other reports (eg Duckett 1998) and are only briefly referred to here. In some analyses, a more detailed explanation of the technique used is given to aid in interpretation. Note that separate analyses were carried out for each vegetation type. Pairwise t-tests were used to detect significant differences in some analyses.

2. Vegetation trend within the Halls Creek study area, 1991 – 1997

Several different approaches have been used to examine vegetation trends within the Halls Creek study area. Although each of these are discussed separately in the following text, a simplified overview is presented in Appendix 1.

2.1 Assessment of trend from a pastoral perspective

2.1.1 Frequency analyses

Vegetation changes from a pastoral perspective were initially investigated by examining changes in the total frequency of the major desirable and undesirable grasses in each pasture community over the assessment periods. Judgements made about whether individual species are "desirable", "intermediate" or "undesirable" were based on the usefulness of these species to pastoral production using the framework developed by Payne et al (1974), rather than from a landscape function or biodiversity perspective. Data were examined for two times, 1991-1994 (8 sites) and 1994-1997 (35 sites[1]).

During the 1991-1994 period, the frequency of undesirable species (feathertop) increased significantly while the frequency of major desirable species did not change significantly (Tables 3 and 4). Conversely, during the 1994-1997 period, an overall significant increase in the frequency of desirables was recorded with no significant change in the frequency of undesirables. Significant increases in desirables were noted on the soft spinifex pasture type but not on the black soils.

Table 3: Mean total frequency of major desirable grasses for each pasture community within the Fitzroy area. Significant differences between assessment years have been determined using paired t-tests (∗∗ = 0.001<p≤0.01; ∗ = 0.01<p≤0.05; NS = p>0.05).

Time period	Pasture community	Number of sites	Mean freq desirables			t value & probability	Significance
			1991	1994	1997		
1991-1994	Black soil plains (Mitchell grass)	8	76.5	77.9		-0.600 (p=0.567)	NS
1994-1997	Black soil plains (Mitchell grass)	26		72.4	75.1	-1.754 (p=0.092)	NS
	Soft spinifex	9		69.1	81.9	-2.522 (p=0.036)	∗
	Average across all sites	**35**		**71.5**	**76.9**	**-2.864 (p=0.007)**	**∗∗**

Table 4: Mean total frequency of major undesirable grasses for each pasture community within the Fitzroy area. Significant differences between assessment years have been determined using paired t-tests (∗ = 0.01<p≤0.05; NS = p>0.05).

Time period	Pasture community	Number of sites	Mean freq desirables			t value & probability	Significance
			1991	1994	1997		
1991-1994	Black soil plains (Mitchell grass)	8	14.0	24.3		-2.982 (p=0.020)	∗
1994-1997	Black soil plains (Mitchell grass)	26		21.1	23.8	-1.668 (p=0.108)	NS
	Soft spinifex	9		0.9	1.6	-0.555 (p=0.594)	NS
	Average across all sites	**35**		**15.9**	**18.1**	**-1.754 (p=0.088)**	**NS**

[1] Data from two sites due for reassessment in 1997 could not be analysed. One site was burnt three days prior to reassessment while at the other site no data was collected as the plants were very dry and the site appeared to be vegetated solely by annuals.

Following these initial analyses, frequency analyses were used to show changes in major species over time at individual sites. Sites displaying a large change (positive or negative value greater than twice the mean absolute change for any of the major species) were then highlighted. Site trends were assessed as improvements or declines depending on whether the species showing change were considered desirable or undesirable. As stated previously, data from the Halls Creek region were available for two periods, 1991-1994 and 1994-1997. Separate cutoff levels for the frequency analyses (*i.e*. twice the mean absolute change) were calculated for each time period. Species of intermediate value (such as northern wanderrie grass (*Eriachne obtusa*) and black speargrass (*Heteropogon contortus*)) were not considered in this analysis as the frequency of these species across all sites was low.

Trend assessment results incorporating the major perennial species in the study area are summarised in Table 5. Table 6 summarises the trend results when the undesirable species feathertop (*Aristida latifolia*) was not included in the analyses. Additional analyses excluding feathertop were performed because it has been suggested that the dynamics of this species is influenced by recent seasonal conditions and may not consistently indicate longer term trend (Hall and Lee 1980, Lee *et al*. 1980, Foran and Bastin 1984). It should be noted, however, that feathertop is the only major undesirable species present in the area.

Negative and positive trends were observed during the 1991-1994 assessment period across the study area. Both trends, however, were due to increasing frequencies of perennial plants (increasing desirables in the case of positive trends, and increasing undesirables in the case of negative trends). During the second assessment period (1994-1997), more sites showed positive than negative trends. Again, positive trends resulted from increasing frequencies of desirable species. Negative trends, however, resulted both from increasing undesirables and from decreasing desirables.

Table 5: Summary of trend assessment (frequency analysis technique) for the Halls Creek monitoring sites for two time periods 1991-1994 and 1994-1997.

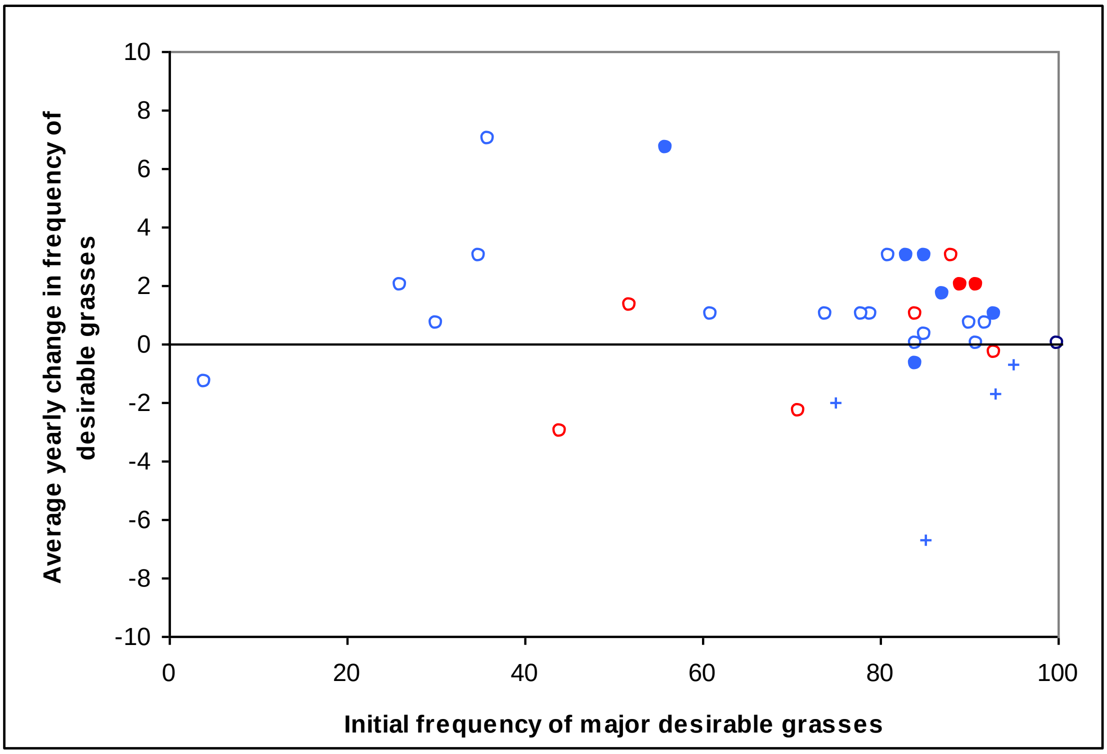
Years	Pasture Community	Total sites	Sites showing positive trend (improving)	Sites showing no change	Sites showing negative trend (declining)	Notes
1991-1994	Black soil plains (Mitchell grass)	8	2	4	2	Improvements due to increasing desirables. Declines due to increasing undesirable feathertop.
	Total	**8**	**2 (25%)**	**4 (50%)**	**2 (25%)**	
1994-1997	Black soil plains (Mitchell grass)	26	6	16	4	Improvements due to increasing desirables and decreasing feathertop. Declines due increasing feathertop and loss of mitchell grass.
	Soft spinifex	9	2	7	0	Improvements due to increasing soft spinifex and silky brown top
	Total	**35**	**8 (22.9%)**	**23 (65.7%)**	**4 (11.4%)**	

Table 6: Summary of trend assessment (frequency analysis technique) for the Halls Creek monitoring sites for 1991-1994 and 1994-1997 when changes in feathertop (*Aristida latifolia*) were not considered.

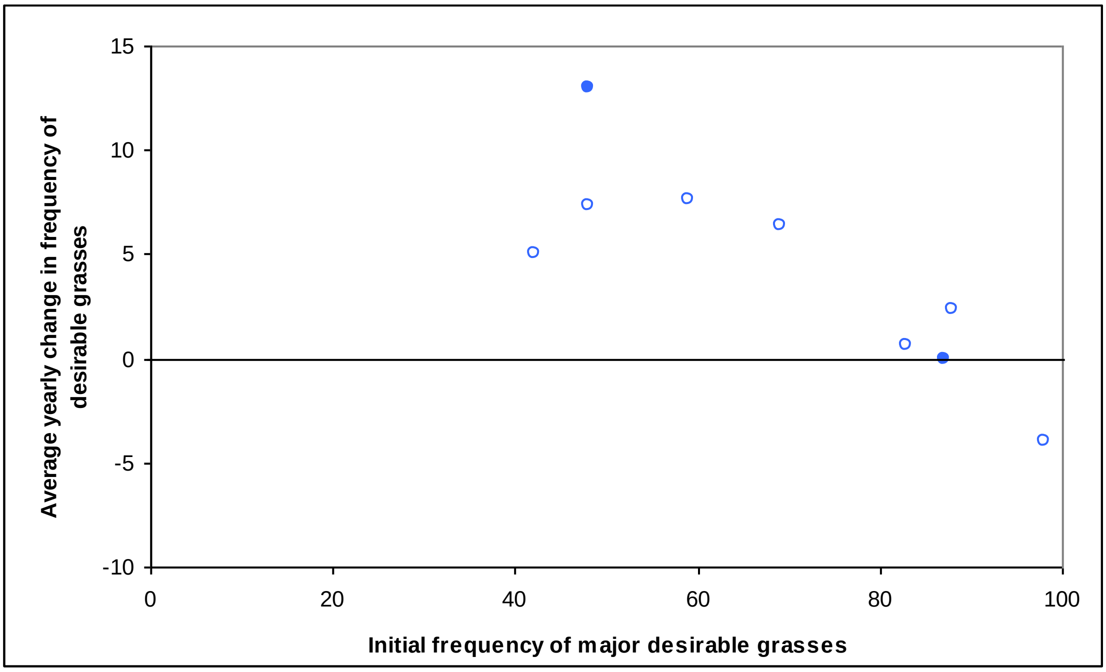
Years	Pasture Community	Total sites	Sites showing positive trend (improving)	Sites showing no change	Sites showing negative trend (declining)	Notes
1991-1994	Black soil plains (Mitchell grass)	8	2	6	0	Improvements due to increasing desirables.
	Total	8	2 (25%)	6 (75%)	0	
1994-1997	Black soil plains (Mitchell grass)	26	6	17	3	Improvements due to increasing desirables. Declines due to loss of mitchell grass. One improving site did show a decrease in native panic and increasing mitchell grass.
	Soft spinifex	9	2	7	0	Improvements due to increasing soft spinifex and silky brown top
	Total	**35**	**8 (22.9%)**	**24 (68.5%)**	**3 (8.6%)**	

Frequency changes can also be illustrated using frequency plots. Firstly, summary plots have been constructed for the black soil and soft spinifex sites (Figure 3). These plots show the relationship between the initial frequency of all major desirable grasses at each site at time X and subsequent changes in frequency from time X to time X+1. Data for revisited sites have been included as separate points for each assessment (1991-1994 and 1994-1997), with frequency changes shown as the average change per year. Sites changes as shown in Table 5 have also been indicated on the plots. These plots show that: (i) there was an increase in the frequency of perennials at a majority of sites, and (ii) a large number of the detected changes (both positive and negative) occurred at sites with initially high frequencies of perennials.

Individual species frequency plots for the black soil sites are shown in Figure 4. These simplified plots do not show frequency values; instead axes have been similarly scaled to make comparisons easier. In this instance, the x-axes represent the initial frequency for each species with the scale ranging from 0-100. Low (0-20), medium (40-60) and (80-100) high frequency categories have been assigned arbitrarily to assist with the description of changes. The y-axes represent the change in frequency from time 1 to time 2. The scale for these axes range from 0-30 in the examples given; this value may change in the future analyses if larger changes over time are recorded. The simplified species plots provide more species-specific information than the summary plots (Figure 3). For example, Figure 4a indicates that the two sites showing decreasing frequencies of barley/hoop mitchell grass (negative or declining trend) had medium to high frequencies of these species at the beginning of the assessment period. In contrast, the two sites showing increasing frequencies of barley/hoop mitchell grass, had medium and low frequencies respectively.



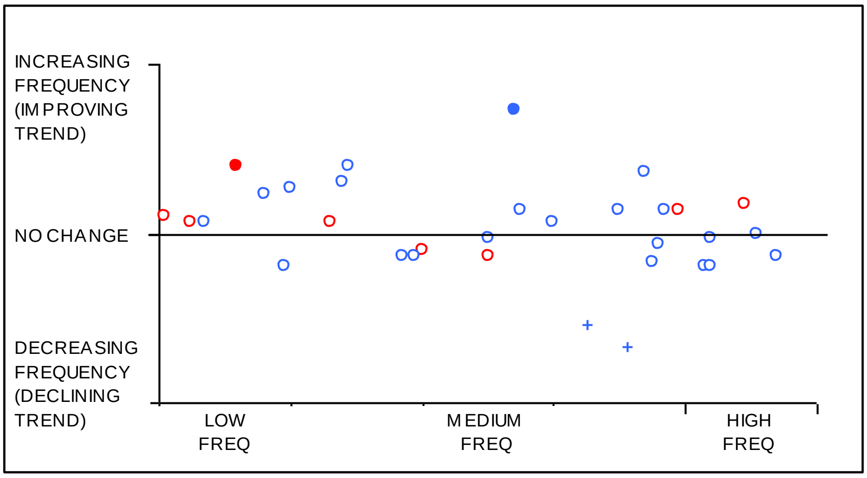
a. Black soil plains (Mitchell grass) sites



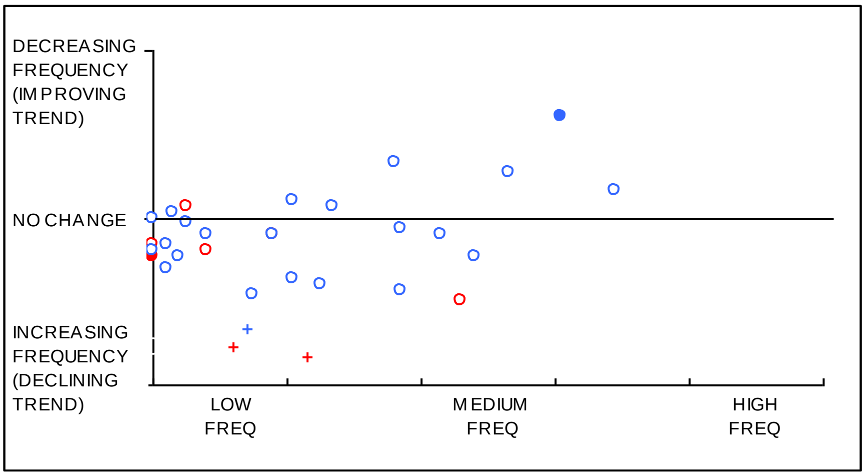
b. Soft spinifex sites

Figure 3: Frequency plots illustrating changes in frequency of major desirable species at monitoring sites within the two pasture communities. The x-axis represents the total initial frequency of major desirable grasses while the y-axis represents the change in frequency from time X to time X+1. Two monitoring periods have been included and are coded as red (1991-1994) and blue (1994-1997).

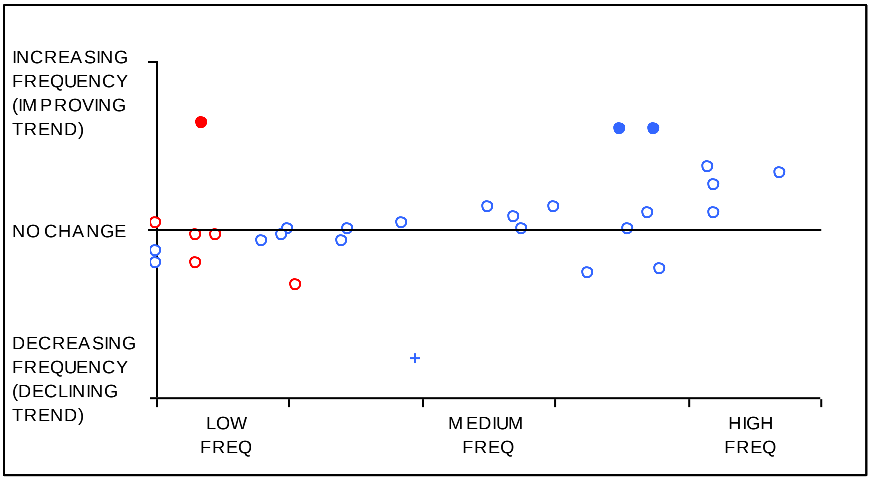
The individual site changes referred to in Table 5 have been indicated on the plot. These changes have been calculated for each pasture community separately using standard frequency analysis techniques. These analyses included *Aristida* species data. Changes are shown as: clear circle = site not changed; solid circle = positive trend; cross = negative trend.



a. Barley mitchell grass (*Astrebla pectinata*) and hoop mitchell grass (*A. elymoides*) – both highly desirable for cattle production purposes.



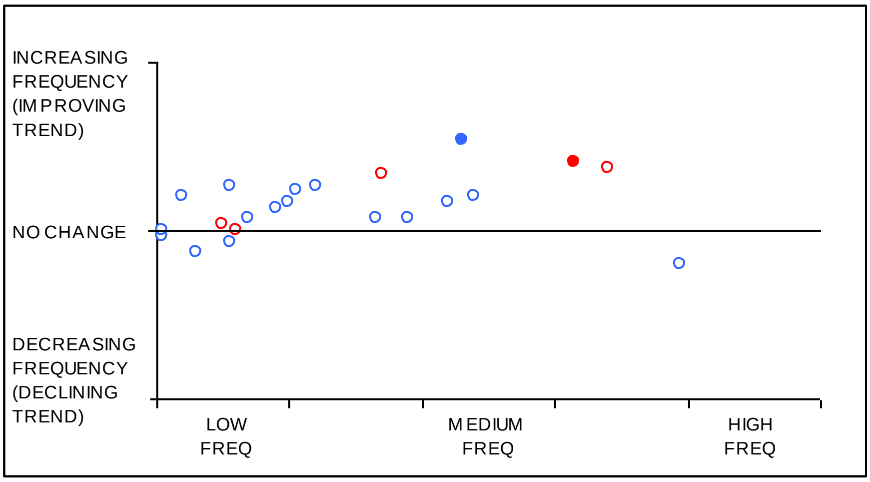
b. Feathertop (*Aristida latifolia*) – undesirable for cattle production purposes.



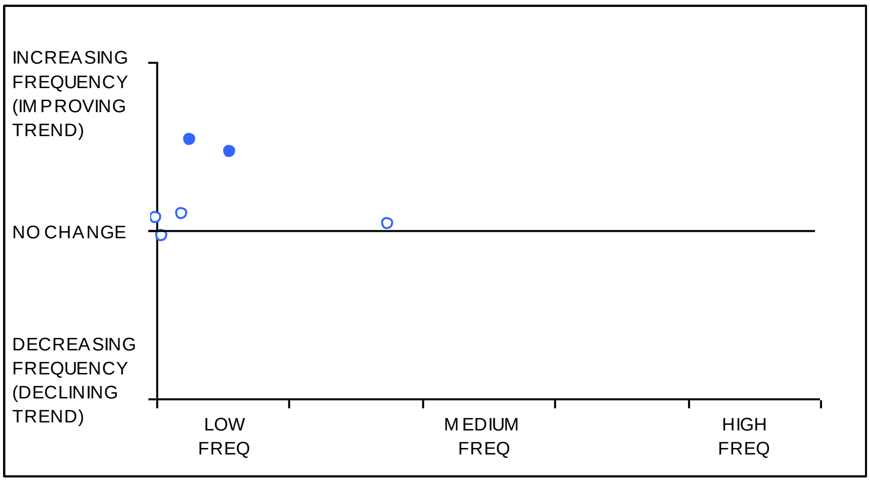
c. Native panic (*Panicum decompositum*) – desirable for cattle production purposes.

Figure 4: Frequency plots illustrating changes in frequency of three of the major perennial species (or groups of species) for the black soil monitoring sites. The x-axis represents the initial frequency for each species (scale ranges from 0-100) while the y-axis represents the change in frequency (scale ranges from 0-30). Two monitoring periods have been included and are coded as red (1991-1994) and blue (1994-1997).

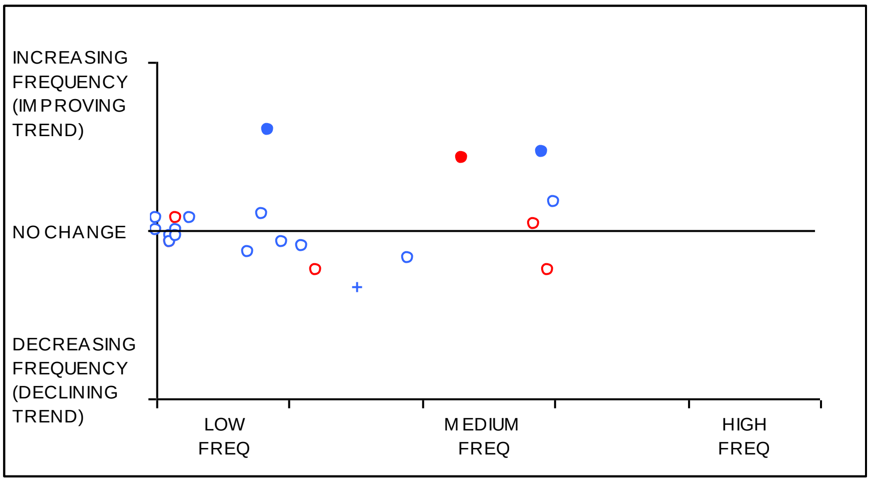
The significance of changes in each species were determined using standard frequency analysis techniques. Changes have been coded as follows: clear circle = site not changed for this species; filled circle = positive trend for this species; cross = negative trend for this species.



d. Ribbongrass (*Chrysopogon fallax*) –highly desirable for cattle production purposes.



e. Bundle bundle (*Dichanthium fecundum*) – desirable for cattle production purposes.



f. Bull mitchell grass (*Astrebla squarrosa*) – desirable for cattle production purposes.

Figure 4: Frequency plots illustrating changes in frequency of three of the major perennial species (or groups of species) for the black soil monitoring sites. The x-axis represents the initial frequency for each species (scale ranges from 0-100) while the y-axis represents the change in frequency (scale ranges from 0-30). Two monitoring periods have been included and are coded as red (1991-1994) and blue (1994-1997).

The significance of changes in each species were determined using standard frequency analysis techniques. Changes have been coded as follows: clear circle = site not changed for this species; filled circle = positive trend for this species; cross = negative trend for this species.

2.1.2 Ordination analyses

2.1.2.1 Methodology

Ordination analysis is an alternative method for examining vegetation trends which allows all species information to be included simultaneously. This technique uses vectors of trend (change) across ordination spaces, and has previously been applied to data from various rangeland communities (*e.g.* Foran *et al.* 1986, Martens *et al.* 1990). Vegetation trends can be determined via ordination analysis of either the full data (species frequencies for all assessments) or the change data (change in frequency between assessments). Ordinations are carried out using the multidimensional scaling technique known as SSH (semi-strong hybrid MDS).

Vegetation trends are determined from the ordination scores generated during the ordination analysis. As no formal statistical test is available, the amount of change (or trend) at each site is related to the length of each of the ordination axes. For the full ordinations, a site is said to have changed if the length of the trend vector (i.e. the line joining the site at time 1 and time 2 in the ordination space) on any axis is greater than 5% of the relevant axis' total length multiplied by the number of years of measurement. For the change ordinations, 'change' is indicated at sites with an ordination score that is greater than 5% of the relevant axis' total length multiplied by the number of years of measurement. These cut-off levels have been chosen as suitable given the current ecological understanding of the plant communities examined to date.

The direction of trend is determined firstly by relating the ordination axes to changes in the frequency of major species. This is done by carrying out Spearman rank correlations between the frequency values for each of the major species at each site with the SSH axis scores for that site (probabilities of ≤ 0.05 are considered significant). The major vegetation gradients acting across the ordination are then determined and movements along each axis classed as positive, negative or neutral (depending on the desirability of the changes in the context of the interpretation). The direction of individual 'changed' sites is then assessed in a similar manner. Note that the raw data for sites showing change are always checked to confirm the interpretation.

Ordination analyses to assess vegetation trend were carried out for the black soil plains vegetation type only, with the data from all three assessment dates (1991, 1994 and 1997) analysed simultaneously. Analyses restricted to the perennial grass frequency data. Data for other perennials (eg forbs and sub-shrubs) were not included as these species appeared to be inconsistently measured and therefore may have added considerable noise to the ordination output. Analyses were carried out using both the full data (plant frequencies for each date included separately) and the change data (changes in frequency for each assessment period). As with the frequency analysis, barley mitchell grass (*A. pectinata*) and hoop mitchell grass (*A. elymoides*) were combined into a single taxa.

2.1.1.1 Results

Ordination was generally unsuccessful for assessing vegetation trend in this instance. Both the extent and direction of trend proved to be very difficult to determine despite re-running of analyses with modified datasets (*e.g.* removal outlier sites, removal of species *etc*). The number of sites changing (*i.e.* those with changes greater than the pre-defined cutoff level of 5% of the axis length per year) varied greatly depending on which species and sites were included - changes occurred at between 11-39% of sites (full data) and up to 96% of sites (change data). Assessment of trend direction was also difficult because the ordination axes could not be simply related to the frequencies of individual species. This complexity most likely arose from the high degree of autocorrelation between many of the species and particularly, the high degree of positive correlation between the frequency of feathertop (*Aristida latifolia*, the only undesirable) and the frequencies of several of the desirable species.

To further examine site changes, a simple plot of changes in the frequency of desirable species (mitchell grass, ribbongrass, bundle bundle and native panic) and undesirable species (feathertop) was constructed

(Figure 5). This plot indicates that a majority of sites increased in both desirables or undesirables over the assessment period, with a number of sites showing both increasing desirables and undesirables. Frequency changes of more than 5% per year were observed at 3 sites for the 1991-1994 period and at 6 sites during the 1994-1997 period. All changes from 1991-1994 could be considered as declines while 4 sites improved and 2 sites declined from 1994-1997 (using increasing desirables/ decreasing undesirables as indicators of positive trend and decreasing desirables/increasing undesirables as indicators of negative trend).

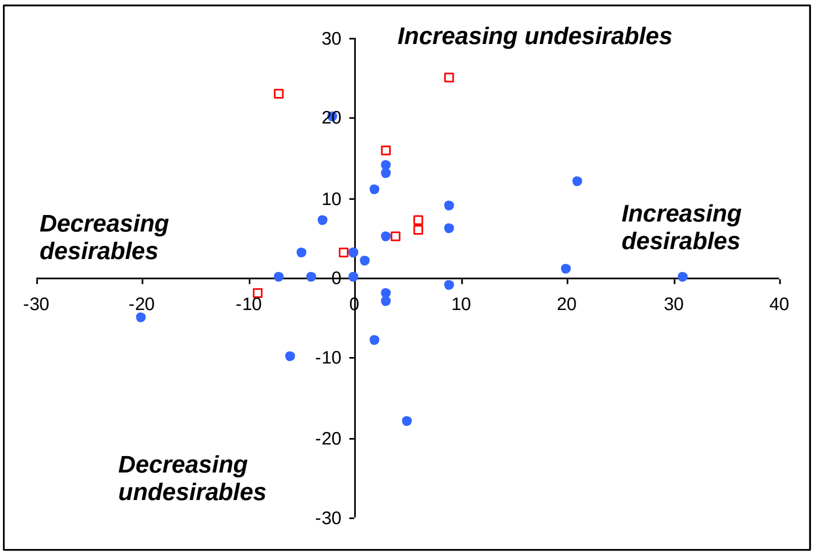


Figure 5: Plot illustrating the relationship between the change in frequency of desirables versus undesirables for all revisited sites for both monitoring periods.

2.2 Assessment of trend from a landscape function perspective

Current research suggests that the optimum functioning of a landscape is reliant on vegetation mounds or patches to regulate rainfall, surface water and litter (Ewel 1997, Tongway and Ludwig 1997). Without these patches, landscape function is reduced due to nutrients and water being lost from the system. Conversion into biomass is probably reduced (although little empirical evidence of this - but see Holm and Watson 2000 (in prep.)). In this analysis, the total frequency of perennial plants has been used as a crude indicator of landscape function. An increase in the total frequency of perennial plants has been regarded as an increase in landscape function. Conversely, a decrease in total perennials suggests reduced function.

Landscape function analysis within the study area was carried out for two periods 1991-1994 (black soil vegetation type only) and 1994-1997 (black soil and soft spinifex vegetation types). The raw frequency totals suggest that there was a slight but not statistically significant increase in perennial grass frequencies from 1991 to 1994 (p=0.29). Significant increases in perennial grass frequencies were indicated from 1994 to 1997, with significant increases in both the black soil and soft spinifex communities (Table 7). This increase was especially notable at the soft spinifex sites where the average frequency increased by 12.1%. Similar increases were noted in the average frequency of all perennial species, although the increases in the black soil pasture were not statistically significant (Table 8).

Table 7: Mean total frequency of perennial grasses for each pasture community within the study area for the two monitoring periods. Significant differences between years have been determined using paired t-tests (∗∗ = 0.001<p≤0.01; ∗ = 0.01<p≤0.05; NS = p>0.05).

Years	Pasture community	Number of sites	Mean frequency of perennial grasses			t value and probability	Significance
			1991	1994	1997		
1991 – 1994	Black soils	8	78.8	85.0		-1.137 (p=0.293)	NS
1994 – 1997	Black soils	26		77.6	81.8	-2.134 (p=0.043)	∗
	Soft spinifex	9		72.8	84.9	-2.360 (p=0.046)	∗
	Total	**35**		**76.3**	**82.6**	**-3.094 (p=0.004)**	**∗∗**

Table 8: Mean total frequency of all perennials for each pasture community within the study area for the two monitoring periods. Significant differences between years have been determined using paired t-tests ((∗∗ = 0.001<p≤0.01; ∗ = 0.01<p≤0.05; NS = p>0.05).

Years	Pasture community	Number of sites	Mean frequency of perennials			t value and probability	Significance
			1991	1994	1997		
1991 – 1994	Black soils	8	78.8	85.0		-1.137 (p=0.293)	NS
1994 – 1997	Black soils	26		80.7	84.4	-1.743 (p=0.094)	NS
	Soft spinifex	9		76.0	87.6	-2.428 (p=0.041)	∗
	Total	**35**		**79.5**	**85.2**	**-2.799 (p=0.008)**	**∗∗**

Frequency analysis was used to highlight those sites showing large changes in the total frequency of perennials. In this instance, analyses were carried out by firstly calculating the frequency of all perennial plants at each site. The change in frequency between visits at each site was then determined, and compared to the mean absolute frequency change across all sites for that vegetation type. As with previous frequency analyses, sites showing a positive or negative change greater than twice the mean absolute change were then defined as having ‘changed’.

The summary frequency plot for the landscape functioning analysis on black soil sites is shown in Figure 6. This graph illustrates two major points:

(i) many sites had very high frequencies (>90%) of perennial grasses in the first year of measurement; these sites would be unlikely to indicate increasing LF by this methodology, and

(ii) the three sites showing increased LF had a medium original frequency of desirable perennial grasses while the two sites showing decreased LF had high original frequencies.

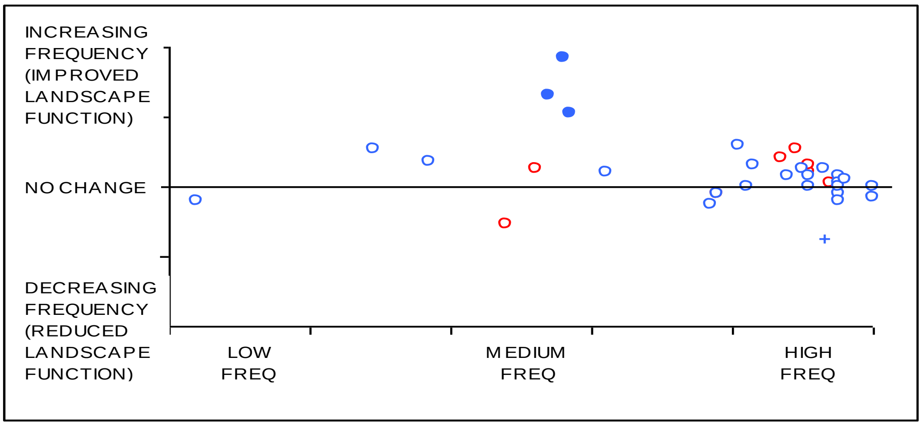


Figure 6: Frequency plot illustrating the change in total frequency of perennial grasses for the black soil monitoring sites. The x-axis represents the initial frequency for each species (scale ranges from 0-100) while the y-axis represents the change in frequency (scale ranges from 0-40). The two monitoring periods have been included and are coded as red (1991-1994) and blue (1994-1997). Individual site changes have been shown as: clear circle = site not changed; solid circle = positive trend; cross = negative trend.

Trend assessment results for landscape function are summarised in Table 9. This table summarises changes in the frequency of perennial grasses, with assessments including all perennial species shown in brackets. The perennial grass frequency data were used as the primary source of data in this instance because of possible inconsistencies associated with the collection and identification of small perennial forb and sub-shrub data. Table 9 indicates that there was no detectable change in the total frequency of perennials (and hence landscape function) at any site during the 1991 – 1994 assessment period. In comparison, improved landscape function was suggested at 4 sites and reduced landscape function at 1 site during the 1994 – 1997 assessment period.

Table 9: Summary of trend assessment from a landscape function perspective for the study area monitoring sites. Analyses have generally been carried out using the total frequency of perennial grasses. Square bracketed numbers indicate changes to trend assessments following the inclusion of perennial forbs and sub-shrubs into the analysis.

Years	Pasture community	Number of sites	Sites with increasing total perennials (improved landscape function)	Sites showing no change	Sites with decreasing total perennials (reduced landscape function)
1991 – 1994	Black soils	8	0	8	0
	Total	**8**	**0**	**8 (100%)**	**0**
1994 - 1997	Black soils	26	3	22 [21]	1 [2]
1994 – 1997	Soft spinifex	9	1	8	0
	Total	**35**	**4 (11.4%)**	**30 (85.7%)**	**1 (2.9%)**

2.3 Changes in woody overstorey cover

Crown cover estimates were carried out in 1994 and 1997. Table 10 summarises the average total crown cover for each vegetation type and also indicates changes in *Acacia* and *Eucalyptus* cover at the soft spinifex sites. Paired t-tests were carried out to determine significant differences between years.

The results indicate that while there was an overall increase in the average woody crown cover from 0.84% in 1994 to 1.54% in 1997, this increase may only be considered borderline in terms of statistical significance (p=0.54). While no change was detected across the black soil sites, significant increases in total woody species did occur across the soft spinifex sites (p=0.044). Separate analyses carried out for *Acacia* and *Eucalyptus* species suggest that both of these groups of species did increase over the 3 year monitoring period (p=0.047 and 0.030 respectively). Interestingly, the 1997 data indicate *Acacia* species on 2 sites previously not known to have these species.

Table 10: Average crown cover estimates for all woody species > 1 m in height at the Halls Creek study sites in 1994 and 1997. Measurements were made using a Bitterlich gauge and averaged over 6 readings. Significant differences between assessment years have been determined using paired t-tests (∗ = 0.01<p≤0.05; NS = p>0.05).

Pasture community	Species included	Number of sites	Crown cover %		t value and probability	Significance
			1994	1997		
Black soils	All species	26	0.042	0.032	0.935 (p=0.359)	NS
Soft spinifex	*Acacia* spp	9	0.62	2.45	-2.340 (p=0.047)	∗
	Eucalyptus spp.	9	2.00	2.98	-2.640 (p=0.030)	∗
	Other woody species	9	0.50	0.47	0.183 (p=0.860)	NS
	All species	9	3.15	5.91	-2.394 (p=0.044)	∗
All sites	**All species**	**35**	**0.84**	**1.54**	**-1.997 (p=0.054)**	**NS**

3. Vegetation trend within the Mt Ramsey/Dixon Range area, 1995/96 - 1998

Some analyses were also carried out using the 1995/96-1998 East Kimberley WARMS assessments data for comparative purposes. While each of these are discussed separately in text, a simplified overview is presented in Appendix 2. As indicated earlier, this data has been collected from an area north west of the Halls Creek study area identified in this report as the Mt Ramsey/Dixon Range area.

3.1 Assessment of trend from a pastoral perspective

Frequency analysis from a pastoral perspective was carried out for the 26 sites included in the assessment area. Trend assessment results for the four pasture communities represented in the dataset are summarised in Table 11. This table also indicates the differences in trends if the intermediate species northern wanderrie grass (*Eriachne obtusa*) and black speargrass (*Heteropogon contortus*) were considered in the analysis. Table 12 summarises the trend results if the undesirable *Aristida* species feathertop and threeawn were not included in the analyses. For the limestone grass pasture community, limestone grass (*Enneapogon polyphyllus*) was included in both analyses despite its classification as an annual species: no site changes resulted from changes in this species. Trends for the curly spinifex/ribbongrass group have been judged subjectively from the raw data for both analyses.

When all major perennial species were considered, more negatively-trending sites were observed than positively trend sites. However, a majority of these negative trends were due to increases in undesirable *Aristida* species, rather than decreases in desirables (Table 11). Interestingly, the only decline noted if *Aristida* species were not included in the analyses was in the southern ribbongrass pasture community. Although not considered in the analyses, large decreases in the annual species limestone grass were noted at a number of sites in the limestone grass and southern ribbongrass communities.

Table 11: Summary of trend assessment (frequency analysis technique) for the Mt Ramsey/Dixon Range monitoring sites assessed in 1995/96 and 1998. Bracketed numbers indicate changes to trend assessments with the inclusion of intermediate species into the analyses. The summary totals and percentages given in the last row of the table are from the analysis excluding intermediates.

Pasture Community	Total sites	Sites showing positive trend (improving)	Sites showing no change	Sites showing negative trend (declining)	Notes
Limestone grass	12	1	9	2	Improvement due to an increase in the desirable ribbongrass (evidence of fire at the site). Declines due to increases in the undesirable threeawn.
Black soil plains (Mitchell grass)	6	2	3	1	Improvements due to increasing desirables. Decline due to an increase in the undesirable feathertop. One site burnt.
Southern ribbongrass	7	0 [2]	4 [2]	3	Declines due to loss of desirables, and increasing feathertop. Two sites with increases in intermediate species - northern wanderrie grass black speargrass
Curly spinifex/ ribbongrass	1	0	0	1	Trend assessed directly from raw data. Site declining due to increasing feathertop & threeawn
Total	**26**	**3 (11.5%)**	**16 (61.5%)**	**7 (27%)**	

Table 12: Summary of trend assessment for the Mt Ramsey/Dixon Range sites assessed in 1995/96 and 1998 when changes in feathertop (*Aristida latifolia*) and threeawn (*A.inaequiglumis*) are not considered. Bracketed numbers indicate changes to trend assessments with the inclusion of intermediate species in the analyses. The summary totals and percentages given in the last row of the table are from the analysis excluding intermediates.

Pasture Community	Total sites	Sites showing positive trend (improving)	Site not changing	Sites showing negative trend (declining)	Notes
Limestone grass	12	1 [2]	11 [10]	0	Improvement due to an increase in the desirable ribbongrass (evidence of fire at the site). The intermediate species black speargrass also increased at one site.
Black soil plains (Mitchell grass)	6	2	4	0	Improvements due to increasing desirables. One site burnt.
Southern ribbongrass	7	0 [2]	6 [4]	1	Decline due to loss of desirables. Two sites with increases in the intermediate species northern wanderrie grass and black speargrass.
Curly spinifex/ ribbongrass	1	0	1	0	Trend assessed directly from raw data.
Total	**26**	**3 (11.5%)**	**22 (84.5%)**	**1 (4%)**	

3.2 Assessment of trend from a landscape function perspective

Landscape function analysis was carried out for the four pasture communities within the Mt Ramsey/Dixon Range area. The frequency totals suggest that there were significant increases in perennial frequencies at sites measured in 1995 and 1998 (p=0.010) and sites measured in 1996 and 1998 (p=0.025, Table 13). This table also suggests that the increases were observed in every pasture community, with significant increases noted for the limestone grass (p=0.044) and southern ribbongrass communities assessed in 1996 and 1998.

Table 13: Mean total frequency of all perennials for each pasture community within the Mt Ramsey/Dixon Range area. Significant differences between years have been determined using paired t-tests. . Significant differences between assessment years have been determined using paired t-tests (∗ =0.01<p≤0.05; ∗∗ = 0.001<p≤0.01; NS = p>0.05).

Pasture community	Number of sites	Mean frequency of perennials			t value and probability	Significance
		1995	1996	1998		
Limestone grass	12	58.25		67.08	-2.275 (p=0.044)	∗
Black soil plains (Mitchell grass)	4	85.5		89.0	-1.206 (p=0.314)	NS
	2		72.5	74	-	
Southern ribbongrass	2	85		95.5	-	
	5		63.4	74	-2.900 (p=0.044)	∗
Curly spinifex/ ribbongrass	1		84	91	-	
Total 1995-1998	**18**	**67.28**		**75.11**	**-2.911 (p=0.010)**	∗∗
Total 1996-1998	**8**		**68.25**	**76.13**	**-2.852 (p=0.025)**	∗

Landscape function trend assessment results using changes in all perennial species are given in Table 14. A majority of the monitoring sites showed no change over the study period. Improved landscape function was suggested at 3 sites while reduced landscape function was not indicated at any sites.

Table 14: Summary of trend assessment from a landscape function perspective for the Mt Ramsey/Dixon Range monitoring sites. Analyses have been carried out using the total frequency of all perennial species.

Pasture community	Number of sites	Sites with increasing total perennials (improved LF)	Sites showing no change	Sites with decreasing total perennials (reduced LF)
Limestone grass	12	1	5	0
Black soil plains (Mitchell grass)	6	2	10	0
Southern ribbongrass	7	0	7	0
Curly spinifex/ ribbongrass	1	0	1	0
Total	26	3 (11.5%)	23 (88.5%)	0

4. Discussion

4.1.1 Trends within the Halls Creek study area, 1991 – 1997

4.1.2 Trends in grasses

Changes in the vegetation at the Halls Creek monitoring sites did occur during both assessment periods. During 1991-1994, there was no significant change in the mean frequency of total perennials or desirables although there was an increase in the frequency of undesirables (feathertop). In contrast, there was a clear increase in the mean frequency of total perennials and perennial grasses from 1994-1997. Significant increases in the frequency of the major desirable grass species were noted while the frequency of undesirables species did not change (Table 15).

Table 15: Mean frequencies of all perennials, perennial grasses, major desirables and major undesirables for Halls Creek sites. Differences between years were detected by pair-wise t-tests.

Assessment Period	Species included	Mean frequency			Significance
		1991	1994	1997	
1991-1994	Perennial grasses	78.8	85.0		NS
	Major desirables in each pasture group	76.5	77.9		NS
	Major undesirables in each pasture group	14.0	24.3		*
1994-1997	All perennials		79.5	85.2	**
	Perennial grasses		76.3	82.6	**
	Major desirables in each pasture group		71.5	76.9	**
	Major undesirables in each pasture group		15.9	18.1	NS

Trend assessment analyses also indicate that a number of individual monitoring sites within the Halls Creek study area had shown vegetation trend (or change) over the two assessment periods. During the 1991-1994 period, frequency analyses suggested that a similar proportion of sites had shown positive trend and negative trend. Depending on the interpretation criteria used, frequency analyses indicated that 0-25% of sites had shown positive trend (improvement), 50-100% of sites had not changed and 0-25% of sites had shown negative trend (decline; Table 16). Site changes were due to increasing frequencies of perennial plants, with the negative trends due to increases in the undesirable feathertop. Notable decreases in desirable perennials were not observed at any site.

In comparison, during the 1994-1997 period analyses suggested that more sites had shown positive trend than negative trend. Analyses indicated that 11.4-22.9% of sites had shown positive trend, 65.7-85.7% of sites had not changed and 2.9-11.4% of sites had shown negative trend. While similar proportions of black soil and soft spinifex sites were indicated as improving, the proportion of declining sites varied with pasture type (Table 17). No soft spinifex sites recorded a decline, although negative trends were noted for 3.8-15.4% of black soil sites. In contrast to the first assessment period, positive trends resulted from increases in desirables and decreases feathertop, while negative trends were due to decreases in desirables and increases feathertop.

As noted in the results tables, the inclusion or exclusion of feathertop (*Aristida latifolia*) did influence the assessment of trend. It remains difficult, however, to reach a general agreement on the importance of this species from a long term pastoral perspective. While some researchers clearly see this species as an undesirable and invasive grass (e.g. Payne *et al.* 1974, Phelps 1999), others have indicated that an increase in feathertop may not always indicate a lasting negative trend. They suggest that an increase in the frequency of feathertop is likely to be short-lived if the increase is a direct consequence of good season conditions (Hall and Lee 1980, Lee *et al.* 1980, Foran and Bastin 1984). As a result, all analyses results have been presented to allow the reader to make their own judgement with regard to this species.

Table 16: Summary of the trend assessment analyses for the Halls Creek monitoring sites. Trends were assessed by frequency analyses using the interpretation criteria indicated. Results are shown as % of the total number of sites.

Time period	Perspective	Interpretation criteria	% of sites showing positive trend (improving)	% of sites not changing	% of sites showing negative trend (declining)
1991-1994	Pastoral	*Aristida* included	25	50	25
		Aristida excluded	25	75	0
	Landscape function	Perennial grasses included	0	100	0
1994-1997	Pastoral	*Aristida* included	22.9	65.7	11.4
		Aristida excluded	22.9	68.5	8.6
	Landscape function	Perennial grasses	11.4	85.7	2.9
		All perennials	11.4	82.9	5.7

Table 17: Summary of the trend assessment analyses for each of the pasture communities in the Halls Creek study area. Trends were assessed by frequency analyses using the interpretation criteria indicated in Table 10. Results are shown as % of the total number of sites.

Time period	Pasture community	Number of sites	% of sites showing positive trend (improving)	% of sites not changing	% of sites showing negative trend (declining)
1991-1994	Black soils	8	25	50-75	0-25
1994-1997	Black soils	26	11.5-23.1	61.5-84.6	3.8-15.4
	Soft spinifex	9	11.1-22.2	77.8-88.9	0

While it is not the brief of this study to determine causality for the detected changes, a few brief comments may be made in this regard. Firstly, it appears likely that some of these general observations may be linked, at least in part, to good seasonal conditions experienced in this area during the 1990's. Rainfall records for Halls Creek show that wet season (November to March) rainfall totals were above average for all years between 1991 and 1997 except 1992 (Figure 7). These higher than average rainfalls are likely to have aided increases in the frequency of all perennial species, both desirable and undesirable. It is unlikely, however, that the trends detected by the frequency analysis are due solely to these favourable seasonal conditions. This is because the individual site frequency changes are determined against an average for each study area, which is likely to reduce some of the seasonal effect.

Figure 7: Annual rainfall totals for Halls Creek A.M.O. (Bureau of Meteorology site 2012). Long term average rainfall extracted from climatic average information on the Bureau of Meteorology website.

4.1.2.1 Trends in woody shrubs and trees

The results suggest that there was a little overall change in the woody crown cover across all monitoring sites within the study area. However, while black soil sites showed little change, significant increases were detected on the soft spinifex sites where increases were seen in *Acacia*, *Eucalyptus* and total crown cover.

It is likely that much of the detected increase on soft spinifex sites may be due to regeneration of shrubs and trees following fire. Large increases in crown cover (>5%) were recorded at two monitoring sites in particular; there was evidence of recent fires (within 2-3 years) at both of these sites. It is possible that these large increases, and also many of the smaller increases, may be due to increased growth following good seasonal conditions. This is likely to have promoted the vertical growth of juvenile trees and shrubs, and also increased the leaf growth of existing larger shrubs and trees. The appearance of *Acacia* species at two sites not previously vegetated by this genus may represent either a post-fire response (both had evidence of previous fires) or the invasion of these species.

4.2 Trends within the Mt Ramsey/Dixon Range area, 1995/96 – 1998

Trend assessment analyses indicated that a number of individual monitoring sites within the Mt Ramsey/Dixon Range study area changed during the assessment period. Depending on the interpretation criteria used, frequency analyses indicated that 11.5-23.0% of sites had shown positive trend, 53.8-88.5% of sites had not changed and 0-27% of sites had shown negative trend (Table 18). These results are similar to those obtained for the Halls Creek study 1994-1997 assessment period, although higher proportions of sites showing negative trend were recorded for the pastoral analysis including *Aristida*.

As with the Halls Creek analyses, the inclusion/exclusion of feathertop and threeawn in the analyses did influence the trend assessment results. Table 18 also shows varying results given the inclusion/exclusion of intermediate species such as black speargrass and northern wanderrie grass. Again, all analyses have been included to allow the reader to make their own judgement on the importance of these species to long term trend.

Table 18: Summary of the trend assessment analyses for the Mt Ramsey/Dixon Range monitoring sites. Trends were assessed by frequency analyses using the interpretation criteria indicated. Results are shown as % of the total number of sites.

Perspective	Interpretation criteria	% of sites showing positive trend (improving)	% of sites not changing	% of sites showing negative trend (declining)
Pastoral	*Aristida* included / intermediates excluded	11.5	61.5	27.0
	Aristida and intermediates included	19.2	53.8	27.0
	Aristida and intermediates excluded	11.5	84.5	4.0
	Aristida excluded / intermediates included	23.0	73.0	4.0
Landscape function	All perennials included	11.5	88.5	0.0

In contrast to the Halls Creek study, seasonal conditions within the Mt Ramsey/Dixon Range area varied from good early in the assessment period to reasonably poor in 1998. Field officers reported a decrease in the biomass and vigour of desirable grasses at several sites in 1998 and number of sites also showed a decrease in the common annual species, limestone grass. Despite the declining seasonal conditions, the results suggest that the frequency of desirables generally remained stable or increased during the monitoring period.

4.3 Summary

Analytical methods developed during the Natural Heritage Trust funded '*Development of information products for reporting rangeland changes'* project have been employed to investigate vegetation trends in the Halls Creek and Mt Ramsey/Dixon Range areas. This report has been compiled to provide an insight into these analytical tools and also the presentation products now available for assessing and displaying vegetation trends over time.

Trend assessment analyses indicate that most monitoring sites across the Halls Creek study area were stable or improving from 1991-1994 and 1994-1997. Seasonal conditions during these times were generally considered to be favourable. A majority of the monitoring sites within the Mt Ramsey/Dixon Range area were also stable or improving during the 1995-1998 period. However, in comparison to the Halls Creek area (1994-1997), a slightly higher proportion of negatively trend sites was recorded. A decline in seasonal conditions from favourable to reasonably poor was noted during the assessment period.

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Appendix 1: Summary of analyses carried out using the Halls Creek ground monitoring data. In all instances, analyses have been carried out separately for each assessment period and each pasture type. Details of each assessment procedure are provided in text while analysis techniques are discussed further in Duckett (1997).

Analysis Type	Objective	Data Used	Analysis Technique	Results
Vegetation trend assessment (Pastoral perspective)	To investigate changes in the mean frequency of desirable and undesirable perennials over time. • Mean frequency includes only the major grass species from each pasture type.	Frequency of major desirable and undesirable grasses at each site	Pairwise t-tests	Tables 3 and 4
	To highlight sites showing changes in the major pastoral species over time.	Frequency of major perennial grasses each site. *Aristida* species included	Frequency analysis	Table 5 Figure 3 – Graphical display of site changes for the two pasture types. Figure 4 – Graphical display of individual species changes at black soil sites
	To highlight sites showing changes in the major pastoral species (excluding *Aristida*) over time. • *Aristida* species excluded from the analysis as changes in these species may not be indicative of long term change	Frequency of major perennial grasses each site. *Aristida* species excluded	Frequency analysis	Table 6
	To highlight sites showing changes in any perennial species over time. Desirability of change for pastoral land use determined.	Frequency of all perennial species at each site. Black soil sites only.	Ordination	Figure 5 – Graphical display of changes in desirable and undesirables
Vegetation trend assessment (Landscape function perspective)	To investigate changes in the mean frequency of perennial grasses and total perennials across the study area	Frequency of perennial grasses and total perennials at each site	Pairwise t-tests	Tables 7 and 8 Figure 6 – Graphical display of changes in frequency of perennial grasses for black soil sites
	To highlight sites showing changes in the frequency of perennial grasses and total perennials over time.	Frequency of perennial grasses and total perennials at each site	Frequency analysis	Table 9
Woody crown cover assessment	To investigate changes in woody crown cover, *Acacia* crown cover and *Eucalyptus* crown cover across the study area.	Crown cover estimates for all woody species at each site > 1m.	Pairwise t-tests	Table 10

Appendix 2: Summary of analyses carried out using the Mt Ramsey/Dixon Range ground monitoring data. In all instances, analyses have been carried out separately for each pasture type. Details of each assessment procedure are provided in text while analysis techniques are discussed further in Duckett (1997).

Analysis Type	Objective	Data Used	Analysis Technique	Results
Vegetation trend assessment (Pastoral perspective)	To highlight sites showing changes in the major pastoral species over time. • Site changes due to intermediate value species included separately as importance of these species is subject to debate.	Frequency of major perennial grasses each site. *Aristida* species included	Frequency analysis	Table 11
	To highlight sites showing changes in the major pastoral species (excluding *Aristida*) over time. • Site changes due to intermediate value species included separately as importance of these species is subject to debate. • *Aristida* species excluded from the analysis as changes in these species may not be indicative of long term change	Frequency of major perennial grasses each site. *Aristida* species excluded	Frequency analysis	Table 12
Vegetation trend assessment (Landscape function perspective)	To investigate changes in the mean frequency of perennials across the study area	Frequency of perennials at each site	Pairwise t-tests	Tables 13
	To highlight sites showing changes in the frequency of perennials over time.	Frequency of perennials at each site	Frequency analysis	Table 14