

**Assessment of Biodiversity Condition in a
Rangelands
Environment Using Remote Sensing**

CSIRO Sustainable Ecosystems

Centre for Arid Zone Research

Gary Bastin and Dr Craig James

CONTENTS

- Summary2**
- Background 4
- Assessing Land Degradation 4
- Methods..... 7
 - Study Area and Analysis Period..... 7
 - Spatial Database..... 7
 - Data Analysis 8
 - Index of Potential Threats to Biodiversity..... 10
 - Intersect NVIS Vegetation Data with Land System Mapping (Component 6)..... 10
- Results..... 11
 - Component 1 – The distribution of land types (land systems) by distance from water and degree of land degradation 11
 - Component 2 - Measures of landscape geometry of land types important for biodiversity 12
 - Component 3 – Index of Potential Threats to Biodiversity 17
 - Component 4 - Recommendation on a whole landscape approach to using this method in the rangelands..... 25
 - Component 5 - Comments and recommended improvements to the Condition Framework as applied to a rangelands environment..... 26
 - Component 6 - Intersect NVIS Vegetation Data with Land System Mapping..... 28
- References 32

Review of Objectives and OutputsError! Bookmark not defined.

Achievement of MilestonesError! Bookmark not defined.

Variations Required for Future MilestonesError! Bookmark not defined.

Data Management.....Error! Bookmark not defined.

Human Resource Issues.....Error! Bookmark not defined.

Communication AchievementsError! Bookmark not defined.

Other CommentsError! Bookmark not defined.

Listing of AppendicesError! Bookmark not defined.

Summary

The Consultancy Contract with CSIRO specifies the following components delivered in full in a final report by 31st December 2000:

1. The distribution of land types (land systems) by distance from water and degree of land degradation;
2. Measures of landscape geometry of land types important for biodiversity;
3. Index of potential threats to biodiversity based on known species' responses to distance from water and arrangement of land types within the case study area.
4. Recommendation on a whole landscape approach to using this method in the rangelands;
5. Comments and recommended improvements to the Condition Framework as applied to a rangelands environment;
6. Outcomes from the intersection of the land types and land systems with NVIS vegetation data and an analysis of how well the NVIS data capture rangeland diversity.

In this case-study region in central Australia the pastorally more productive land systems, and land systems grouped into broader vegetation types, are more intensively developed with infrastructure for grazing than pastorally less useful country. This means that a low proportion of more productive land types is remote from water and hence lightly grazed. Vegetation types and land systems that contain a high proportion of palatable plants are more degraded than those with less palatable plants when assessed by grazing-gradient satellite analysis.

Contagion and interspersions values, as indices of the spatial arrangement of patches in the landscape, indicate the extent to which both water development and land degradation associated with pastoralism have fragmented habitat types. Non-degraded and water-remote patches of pastorally more productive land systems or vegetation types are more dispersed and more fragmented relative to their original state, than for patches of pastorally less productive land systems or vegetation types.

Species that are intolerant of grazing are predominantly found in water-remote locations. These areas may serve as refugia for such species. The degradation and fragmentation of pastorally more productive habitats may have implications for the persistence of species that are negatively affected by grazing. We tested this hypothesis by examining the correlation between the number of plant species, as a proportion of the total number of species, that have conservation significance in each landsystem or vegetation type, and: (a) the proportional areas of vegetation types that were water-remote; (b) the proportional areas of vegetation types that were not degraded; and (c) interspersions scores measuring the degree of landscape fragmentation at similar distance thresholds.

Some significant correlations were found indicating that plant assemblages of pastorally more productive (and hence more developed, more heavily grazed and more degraded) habitats tend to have higher proportions of species of conservation significance. This result needs confirmation in other areas, and verification that it is not an artefact of the natural plant assemblages in pastorally more productive habitats. Following verification, simple indices based on distance from water and degradation may have value as regional-scale indicators of threat to biodiversity in rangelands.

We expect that analysis procedures applied in this case study are transferable to other rangeland regions where land degradation is likely to be expressed through the persistence of wet-period grazing gradients. Analysis and interpretation of results should be at a broader, rather than finer, scale (e.g. grouped land systems, vegetation associations, and habitats rather than land units).

There is potential to further develop indices of potential threat to the persistence of grazing-affected species by examining similar sorts of data for other taxa in the central Australian case-study region, and in new regions. This study also provides a rationale for the stratification of data collection in future: that is, by habitat and distance from water (or accurate spatial location). Well-stratified

collection of data by a range of field biologists will alleviate a perennial problem in rangeland studies, which is the need for large numbers of specimen records over large areas.

Background

Annual rainfall in central Australia is generally low and highly variable. Most years experience below-average rainfall (long term mean annual rainfall for Alice Springs is 267 mm) and extended dry periods are common. These prolonged dry periods may be interrupted by heavy rains when the monsoonal trough or a rain depression associated with a decaying cyclone penetrates inland Australia. Rainfall can also occur in the cooler winter months and both the timing and amount of rainfall produce large changes in the amount and composition of the herbage layer.

Grazing by beef cattle is the most extensive commercial land use. Paddocks are large (tens to hundreds of square kilometres) and generally contain diverse land types that vary in their acceptability as forage to cattle. Cattle require water to drink every day in the warmer half of the year and are limited in how far from a water point they can travel between drinks (Low *et al.* 1978). Foraging activities of stock can be managed by this dependence on water points, which are separated by several kilometres. Grazing distribution is uneven both in time and space with land types growing the most palatable forage and located close to water having the greatest risk of overgrazing and consequent land degradation. Land degradation can occur through loss of palatable forage species (particularly perennial species), soil erosion, and increased density of unpalatable trees and shrubs (woody weeds). However, the extent and severity of land degradation is difficult to determine because of the large area involved, spatial complexity of land types within paddocks and dramatic short-term changes in vegetation following rainfall (Pickup 1989).

While most plant and animal species are tolerant of grazing, some species are less common where grazing pressure is high, and, in extreme cases, some species only occur at sites with little or no grazing pressure (Landsberg *et al.* 1997). Areas with very light grazing pressure are typically a long distance from water.

Assessing Land Degradation

Grazing effects on the vegetation can be explicitly filtered from the influence of local landscape variability by examining patterns of cover change with increasing distance from water (Pickup *et al.* 1994). The typical pattern is a trend of increasing cover with increasing distance from water – a grazing gradient (Figure 1). Most importantly, the extent to which vegetation cover is restored close to water following good rains is used to judge the long-term impact of grazing on each landscape. In undamaged landscapes, average cover close to water is similar to that at more distant locations after good rains, while in degraded landscapes, the grazing gradient largely persists (Pickup and Chewings 1994).

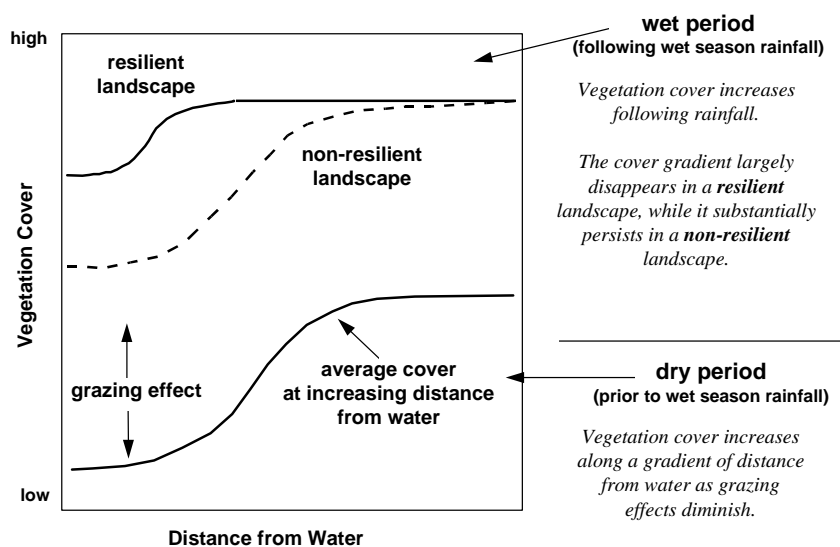


Figure 1. Stylised patterns of cover change with increasing distance from water related to grazing. The bottom curve illustrates cover levels in a dry period while the upper curves show cover responses following rain for undamaged (resilient) and degraded (non-resilient) landscapes. Each trend line represents a grazing gradient.

We explicitly define land degradation as “a grazing-induced reduction in the amount of vegetation cover likely to be present after the best growth conditions experienced within a reasonable time” (Bastin *et al.* 1993). The extent of degradation is specified as a Percentage Cover Production Loss (%CPL) value which is calculated as the difference between the cover level expected if the vegetation fully recovered (dashed line, R, to distance, d_i , in Figure 2) and that which actually occurred, divided by the dry to wet period increase in cover necessary for full recovery. Higher values mean more persistent wet period grazing gradients and greater land degradation. The index allows the effects of grazing management to be compared across paddocks and land types.

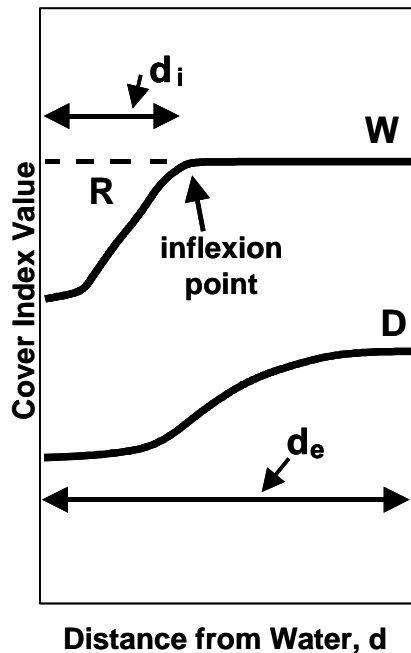


Figure 2. Procedure for calculating the %CPL index. The lower solid line (D) represents dry period cover, the upper solid line (W) shows wet period cover and the dashed line (R) expected cover if the vegetation fully recovered. d_i is the number of distance classes to the inflexion point from water.

The %CPL index is calculated as:

$$\%CPL = A / (A+B) * 100$$

where:

$$A = \sum_{k=1}^{d_i} (R - W_k) n_k$$

$$B = \sum_{k=1}^{d_e} (W_k - D_k) n_k$$

In these equations:

- R is the cover index value expected if the vegetation fully recovered in a wet period;
- W_k is the observed wet period cover index value in distance class k;
- D_k is the observed dry period cover index value in distance class k;
- d_i is the number of distance classes to the inflexion point from water.
The inflexion point is the distance, when approaching water, beyond which wet-period average cover values markedly decrease;
- d_e is the number of distance classes over which the recovery index is to be calculated;
- n_k is the number of pixels in distance class k.

Methods

Study Area and Analysis Period

The Case Study area covers 16 pastoral leases extending from the Tropic of Capricorn (23°S) to the South Australian border (26°S), an area of some 38,000 km² (Figure 3). Assessment of land degradation is based on historical satellite data (Landsat MSS) spanning two periods of major vegetation growth at the regional scale through the 1980s. These were March 1983 when approximately 360 mm rainfall was recorded at Alice Springs and March 1989 when rainfall of similar magnitude was recorded at Erldunda. This second rainfall event was confined to the southern half of the analysis region.

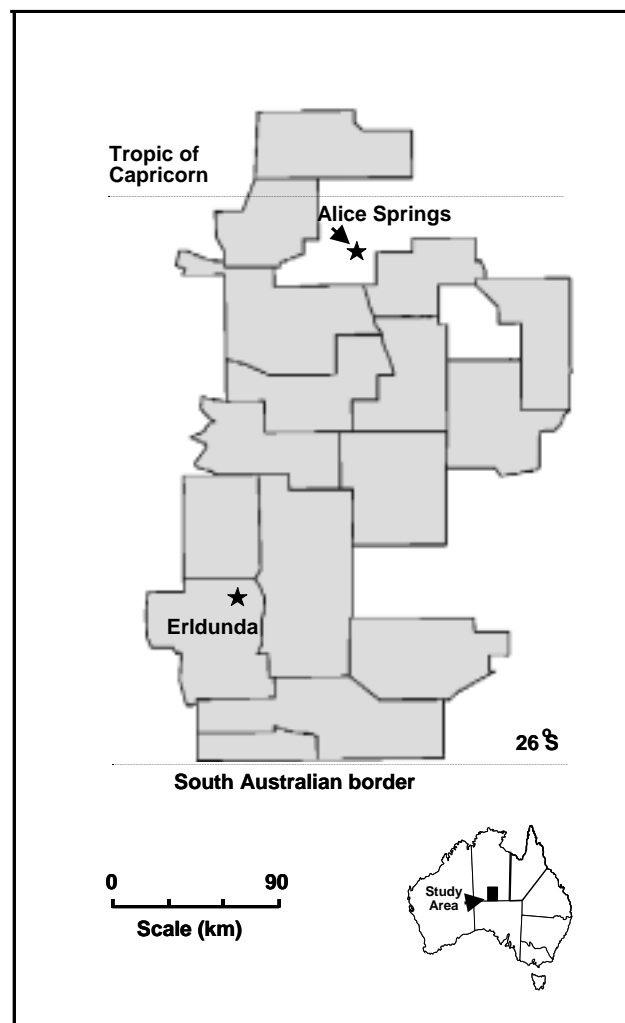


Figure 3. Location and extent of the study area.

Spatial Database

Landsat MSS digital data were acquired for prevailing dry periods before the major rainfall events (October 1982 and February 1988) and about six weeks after them (May 1983 and 1989) when vegetation growth had peaked. The Case Study area is covered by Landsat Path 102 (non-standard framing for Rows 77 & 78). Satellite data were radiometrically standardized, geometrically rectified and resampled to a 1 ha pixel size. The PD54 index (Pickup *et al.* 1993) was then used to calculate multitemporal cover. This index is derived from the radiance properties of soil and vegetation that

form a triangular structure in the four-dimensional Landsat MSS data space. Most of the information relating to vegetation cover in the arid rangelands is captured in Bands 4 (500-600 nm) and 5 (600-700 nm). The upper limit of the Band 4 – Band 5 data space is a line indicating bare soil while points below this line indicate increasing cover to a maximum value at the most distant point from the line.

The digitised locations of fences extracted from orthophotomaps were merged with natural barriers (mountain ranges, high ridges and hills) extracted from a classified Landsat image to form paddocks. The digitised positions of operational waters were then combined with paddock boundaries to calculate the distance of every location (pixel) from its nearest source of water. We then used two levels of landscape stratification to derive grazing gradients. These were (1) pastorally significant areas of land systems mapped at 1:250,000 scale (Appendix 1) and (2) land systems grouped into vegetation types (Appendix 2). Some land systems were subdivided into two major units to better represent grazing use. The aggregation of land systems into vegetation types may better represent how some taxa (e.g. birds) use vegetation at the habitat level.

Data Analysis

Figure 4 provides an overview of data analysis within components 1 to 3. In Component 1, we determined the extent of land degradation for both individual land systems, and land systems grouped into vegetation types. Grazing gradient analysis and %CPL values (Bastin *et al.* 1993) were used to determine the extent of land degradation.

Within Component 2, measures of landscape geometry were derived using ArcView Spatial Analyst and LEAP II (Perara *et al.* 1997). LEAP II is a landscape ecological analysis package available on the web (<http://curie.ei.jrc.it/archives/1999/Ai-03-99/0015.html>). Landscape geometry was calculated at two levels.

1. Proportional areas of each land system or vegetation type (a) within and beyond a threshold distance from water and (b) that is degraded and non-degraded. In (a), we use that area beyond 10 km from water to indicate where grazing pressure is either low and intermittent, or non-existent, to indicate where plant and animal species adversely affected by grazing might persist based on findings in Landsberg *et al.* (1997). In (b), we use the distance from water at which complete recovery in vegetation cover occurs following rainfall as the boundary between degraded and non-degraded areas. This is the inflexion point distance (Figure 2). On average, severity of degradation decreases as the inflexion point is approached. In areas closer to water than the inflexion point, species that increase in response to grazing flourish, whereas those that decrease are likely to be rare or absent.
2. Contagion and interspersions scores for land systems and vegetation types (a) for their total area and (b) for their non-degraded area (i.e. beyond the inflexion point distance where complete recovery in wet-period vegetation cover occurred).

In deriving these values, LEAP II uses naming conventions to indicate patch hierarchy. In this case study, a *patch* is the individual or discrete mapped area of each land system (or grouped land systems within a vegetation type). All patches within a land system (or vegetation type) form a *class* while the entire analysis area is the *landscape* (i.e. comprising many classes and very many patches).

The *contagion index* (Li and Reynolds 1993) measures the clumping (lack of patchiness) or dispersion and interspersions (patchiness) in the landscape. Generally, higher contagion values indicate less patchiness (few smaller patches) and less intermixing (less isolation). Lower contagion values may indicate a “broken up” or fragmented landscape. Index values are reported at the landscape level (i.e. all land systems or vegetation types).

The *interspersions index* (McGarigal and Marks 1995) indicates the intermixing of patches. At the class level, the index is based on the probabilities of a patch of a given class being adjacent to patches of the other classes. A low interspersions index implies less intermixing of patches. An interspersions index that approaches 100% indicates the greatest possible patch intermixing.

Proportional areas from the two distance-from-water stratifications and interspersion index values were then tested for their ability to indicate potential threat to biodiversity (Figure 4 and following section).

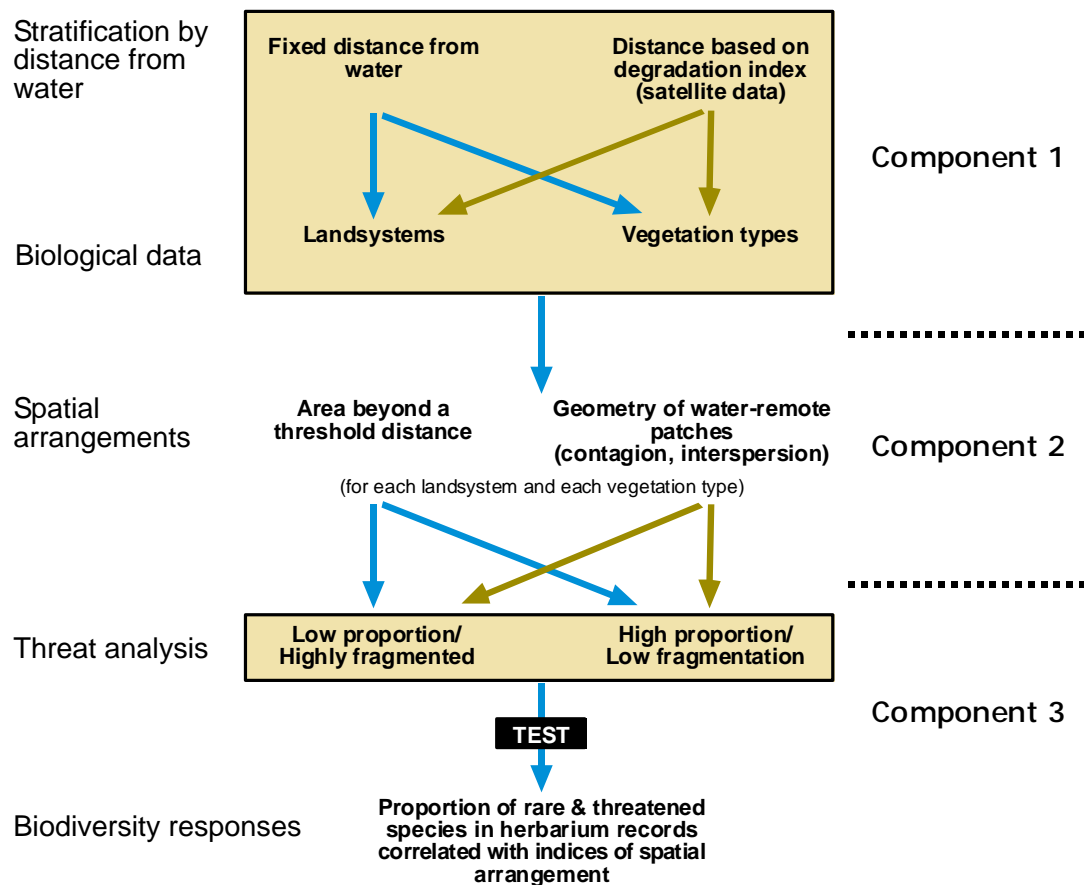


Figure 4. Analysis framework for Components 1-3.

Index of Potential Threats to Biodiversity

Indices of potential threat to biodiversity were derived in two steps (Figure 4). In the first, we calculated proportional areas of each land type (either land system or vegetation type) within and beyond the distance thresholds specified above; i.e., (a) 10 km from water and (b) the inflexion point distance used to specify whether each area was degraded or non degraded. In the second approach, we used the interspersions score for each land type. The utility of each index was tested by correlating index values against proportions and densities of plant species which are either rare or have biological significance within the analysis region. Point locations of all plant-species records were obtained from the NT Herbarium database, including status designation. CSIRO thanks the Parks & Wildlife Commission of the Northern Territory and the Arid Lands Environment Centre for allowing us access to their database of plant collection records, including rare and threatened plants of the southern NT, prior to its publication (White *et al.* in prep.).

Intersect NVIS Vegetation Data with Land System Mapping (Component 6)

ArcInfo coverages of the 1:100,000 scale land unit map of Eraldunda Station (supplied by NT Dept. Lands, Planning & Environment), and the 1:1,000,000 scale vegetation map of the NT (Wilson *et al.* 1990), were imported into ArcView, converted to grid format, and cross-tabulated against the 1:250,000 scale land system map. Pixel size for all analyses was 100 m (i.e. 1 ha).

Results

Component 1 – The distribution of land types (land systems) by distance from water and degree of land degradation

(To simplify the structure within which results are presented (Figure 4), we report on degree of land degradation in this component and distribution of land types with respect to distance from water in Component 2.)

Mapped land systems

Land systems containing a high proportion of palatable forage have high index values and are most adversely affected by grazing (Table 1). These land systems are frequently the most intensively stocked due to their original productivity. In some cases, parts of these land systems have also had a relatively long history of grazing. Some land systems of lower pastoral value show no gradient after rainfall but a pattern of decreasing cover with distance from water after a period of grazing. This is associated with an increase in cover of unpalatable shrubs (Bastin *et al.* 1993).

Table 1. Area and extent of land degradation for land systems. Land systems are arranged in order of decreasing pastoral productivity (based on the stratification of Bastin *et al.* 1993). The “distance to inflexion point” indicates that distance from water beyond which complete recovery in wet period vegetation cover occurred. %CPL values were assigned to arbitrary categories of land degradation severity based on %CPL>14 = severe, 10-14 = high, 5-9 = moderate, 1-4 = slight and %CPL<1 = nil.

Pastoral Productivity	Land System	Area (km ²)	Distance to inflexion point (km)	%CPL value	Land degradation category
Very High	Todd	743.9	5.6	24	severe
	Hamilton	265.6	5.8	9	moderate
	Hamilton Four	65.4	3.8	9	moderate
	Alcoota	196.9	4.2	11	high
High	Ebenezer	1741.1	7.2	9	moderate
	Renners	585.3	2.4	2	slight
	Muller One	544.5	6.2	17	severe
	Allua Two	479.5	3.2	3	slight
	Outounya	944.3	9	6	moderate
	Cavenagh Two	399.5	5.2	7	moderate
	Kalamerta One	323.1	7.4	9	moderate
	Ringwood	1092.8	4	3	slight
	Allua Three	14.6	5.6	14	high
	Moderate	Chandlers	2486.6	1.8	0
Endinda		157.7	1.6	1	slight
Angas		482.7	2.2	0	nil
Lilla		998.3	6.8	9	moderate
Lindavale		979.7	6.6	5	moderate
Kalamerta Two		464.4	2.4	1	slight
Karee		865.6	10.2	9	moderate
Muller Two		328.9	0.8	0	inverse ¹
Finke		648.9	4	7	moderate
Low		Simpson	10181.8	0.8	0
	Ewanninga	1694.7	3.4	0	nil
	Singleton	3025.3	1	0	nil
	Amadeua	354	2.6	2	slight
	Cavenagh One	129.7	2.4	0	nil
	Allua One	188.4	5	12	high
	Bushy Park	1184.4	1	0	nil
	Boen	373	1.2	0	nil
Total		31940			

¹ Wet period average cover shows no gradient after rainfall, but rather a pattern of decreasing cover with distance from water after a period of grazing. This is associated with an increase in cover of unpalatable shrubs. This is particularly the case for Muller Two land system and less so for Simpson land system. It is not possible to calculate a %CPL value for land systems with inverse gradients. However, the inflexion point distance indicates the short distance from water over which cover initially increased and then decreased.

Our analysis excludes mountains and other areas of rugged terrain. These areas are only occasionally and minimally grazed by controlled stock. Land systems with minor occurrence in the Case Study region (Appendix 1) are also not analysed. We have also excluded small paddocks (<20 km²) because all areas are generally close to water and grazing gradients are not well developed.

Land systems grouped into vegetation types

Land systems were grouped into vegetation types (Appendix 2) according to their predominant vegetation. This allowed us to include land systems (or component land units) that individually were too small to analyse for grazing gradients in the previous section. The additional land systems are briefly described in Appendix 2.

The most pastorally productive vegetation types (open woodland plains, alluvial fans and plains, floodouts) have the highest %CPL values (Table 2) and are the most degraded in terms of lack of vegetation recovery following major rainfall. In comparison, pastorally less productive vegetation types (mulga shrublands, hills and foothills, and salt lakes) show almost complete vegetation recovery following rainfall. There is also minimal permanent grazing impact in the sand dunes and plains vegetation type (i.e. desert country).

Table 2. Area and extent of land degradation for land systems grouped into vegetation types (see Appendix 2 for grouping). Vegetation types are arranged in order of decreasing pastoral productivity (based on the stratification of land systems used by Bastin *et al.* 1993). The “distance to inflexion point” indicates that distance from water beyond which complete recovery in wet period vegetation cover occurred. %CPL values were assigned to the same categories of land degradation as used in Table 1.

Past. Prod.	Vegetation type	Area (km ²)	Dist. to infl. point (km)	%CPL value	Land degradation cat.
Very High	alluvial fans & plains (open woodland)	1215.1	6.6	17	severe
	floodouts	920.8	6.2	16	severe
	cracking clay plain	54.3	5	13	high
High	plains with open woodland	325	5.6	50	severe
	calcareous slopes & plains	4487.8	3.4	3	slight
	granitic plains - open woodland	1343.8	5	8	moderate
	saltbush & myall	384.5	4.6	17	severe
	gidyea woodland	1129.8	4.6	5	moderate
Moderate	clayey stony slopes - Chandlers l.s.	2486.6	2.4	1	slight
	foothills, footslopes, colluvial fans & plains	942.8	2.6	2	slight
	southern mulga type	1946.6	7.2	16	severe
Low	sand dunes & plains	14901.8	1		inverse ¹
	salt lakes	354	1.4	1	slight
	hills & ridges	464.8	1.6	1	slight
	mulga shrubland	3395.9	1.8	0	nil
	mulga terraces	144.3	3.2	5	moderate
Total		34497.9			

¹ Not possible to calculate a %CPL value for this vegetation type because of its inverse wet-period gradient. However, the inflexion point distance indicates the short distance from water over which cover initially increased and then decreased.

Component 2 - Measures of landscape geometry of land types important for biodiversity

Land system area by distance from water and degradation

Most of the area of the pastorally-useful land systems are within grazing range of water (Figure 5). Small areas of country with moderate pastoral value are remote from water while significant areas of country with low pastoral value are protected by distance from water. Areas and proportions of land systems beyond our two distance thresholds from water (10 km and inflexion point distance) are

listed in Table 3. These results are similar to those for other pastoral regions of Australia where comparable analyses have been performed.

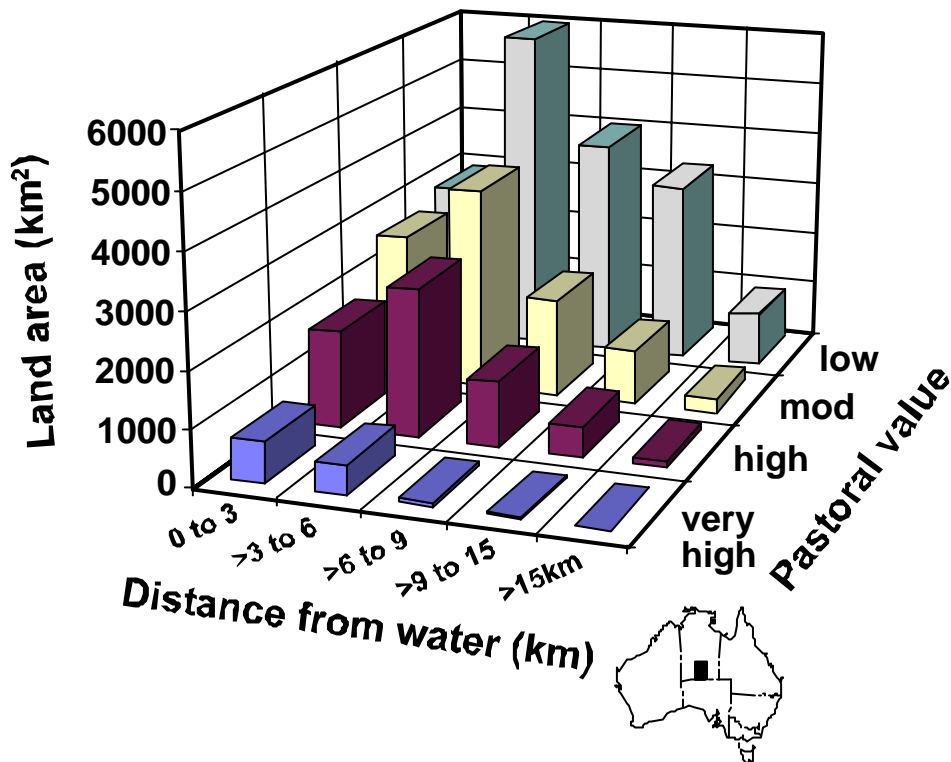


Figure 5. Area of land systems, grouped by pastoral value, at different distance intervals from water.

The implication for species that decline under grazing is that: (1) there is a small proportion of their former range now available, particularly in land systems with high pastoral value; and (2) the remaining areas where populations do occur at normal density, are likely to be widely scattered in the landscape. Further analysis of the change in spatial aspects of the suitability of the landscape for species that respond to grazing is presented below.

Using the distance from water at which wet-period vegetation cover is fully restored as a threshold between degraded and non-degraded areas shows that the less productive land systems generally have a higher proportion of non-degraded country than pastorally more productive land systems (Table 3). The aggregated proportions of non-degraded land systems by pastoral productivity category are: “very high”, 10.7%; “high”, 34.7%; “moderate”, 57.5% and “low”, 95.4%.

Table 3. Land system areas, and proportional areas, at two distance thresholds from water; 10 km and the inflexion point distance beyond which wet-period vegetation cover is completely restored. (PP = pastoral productivity, VH = very high, H = high, M = moderate & L = low)

PP	Land System	Area (km ²)	Area >10 km	% >10 km	Infl. pt. (km)	Not degra. (km ²)	% not degra
VH	Todd	744	1	0.1	5.6	83	11
	Hamilton	266	0		5.8	16	6
	Hamilton Four	65	0		3.8	6	9
	Alcoota	197	1	0.3	4.2	31	16
H	Ebenezer	1741	108	6.2	7.2	322	18
	Renners	585	25	4.3	2.4	431	74
	Muller One	544	10	1.9	6.2	101	19
	Allua Two	479	34	7.1	3.2	274	57
	Outounya	944	94	9.9	9	135	14
	Cavenagh Two	399	3	0.6	5.2	88	22
	Kalamerta One	323	32	10	7.4	62	19
	Ringwood	1093	161	14.7	4	701	64
	Allua Three	15	1	8.6	5.6	10	69
	M	Chandlers	2487	99	4	1.8	2159
Endinda		158	2	1.2	1.6	132	84
Angas		483	78	16.2	2.2	446	92
Lilla		998	1	0.1	6.8	62	6
Lindavale		980	152	15.5	6.6	369	38
Kalamerta Two		464	51	10.9	2.4	395	85
Karee		866	215	24.8	10.2	206	24
Muller Two		329	3	0.8	0.8	323	98
Finke		649	15	2.3	4	166	26
L		Simpson	10182	2327	22.9	0.8	10092
	Ewaninga	1695	269	15.9	3.4	1342	79
	Singleton	3025	640	21.1	1	2980	98
	Amadeua	354	27	7.5	2.6	271	76
	Cavenagh One	130	0	0.4	2.4	118	91
	Allua One	188	5	2.6	5	50	27
	Bushy Park	1184	73	6.1	1	1140	96
	Boen	373	10	2.6	1.2	350	94
Total		31940	4437	13.9		22861	71.6

Vegetation type area by distance from water and degradation

Pastorally more productive vegetation types have a higher proportion of their total area within 10 km of water compared with less productive vegetation types (Table 4). The actual percentages of each category beyond 10 km from water are: “very high”, 1.1%; “high”, 8.4%; “moderate”, 7.0% and “low”, 19.1%. Figure 6 shows how one of the pastorally more productive vegetation types is more intensively watered compared with pastorally less useful “desert” country. More of the highly productive country is close to water and is more intensively grazed because of pastoralists’ preference for developing it compared with pastorally less useful country.

Only a small proportion of the total area of vegetation types with very high pastoral productivity is non-degraded (Table 4). The proportion of total area that is not degraded increases as pastoral productivity declines (“very high”, 8.0%; “high”, 57.4%; “moderate”, 56.1% and “low”, 96.2%).

Table 4. Vegetation type areas, and proportional areas, at two distance thresholds from water; 10 km and the inflexion point distance beyond which wet-period vegetation cover completely recovers. (PP = pastoral productivity, VH = very high, H = high, M = moderate & L = low)

PP	Vegetation Type	Area	Area	% area	Dist infl.	Not degr.	% not
		(sq km)	>10 km	>10 km	pt. (km)	(sq km)	degr.
VH	alluvial fans & plains (open woodland)	1215	8	0.7	6.6	101	8.3
	floodouts	921	17	1.9	6.2	71	7.7
	cracking clay plain	54	0	0	5	3	5.5
H	plains with open woodland	325	8	2.5	5.6	44	13.5
	calcareous slopes & plains	4488	332	7.4	3.4	2941	65.5
	granitic plains - open woodland	1344	96	7.1	5	547	40.7
	saltbush & myall	385	34	9	4.6	219	56.9
	gidyea woodland	1130	174	15.4	4.6	653	57.8
M	clayey stony slopes - Chandlers l.s.	2487	99	4	2.4	1950	78.4
	foothills, footslopes, colluvial fans & plains	943	129	13.6	2.6	705	74.8
	southern mulga type	1947	146	7.5	7.2	363	18.6
L	sand dunes & plains	14902	3237	21.7	1	14680	98.5
	salt lakes	354	27	7.5	1.4	326	92.1
	hills & ridges	465	26	5.5	1.6	382	82.3
	mulga shrubland	3396	349	10.3	1.8	3042	89.6
	mulga terraces	144	39	27.2	3.2	102	70.3
Total		34498	4721			26129	

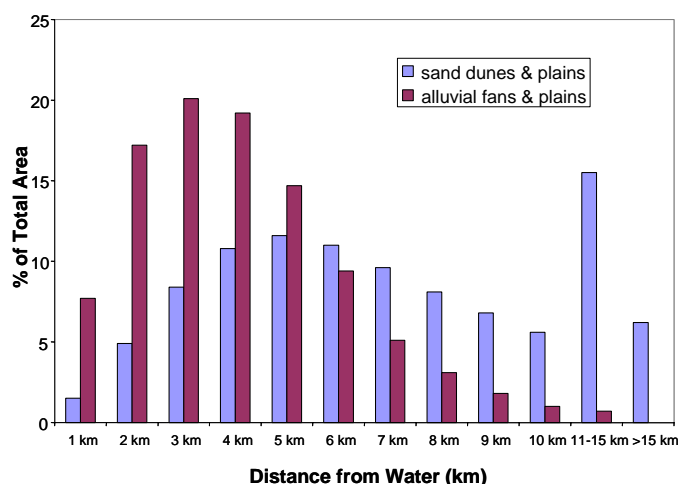


Figure 6. Proportion of the total area of two vegetation types at increasing distance from water. The alluvial fans & plains vegetation type has a higher proportion of palatable forage and is more preferred by grazing cattle than the sand dunes & plains vegetation type.

Contagion and interspersions

For the whole region, values of the interspersions index for both the land system and vegetation type stratifications are lower for the non-degraded areas compared with the total area (Figure 7). There is a greater reduction for the vegetation-type stratification (20.1%) compared with land system stratification (13.3%). This implies that for both stratifications, there is less intermixing of non-degraded patches compared with the total area. The non-degraded area is more homogeneous because it contains a higher proportion of the pastorally less productive land systems or vegetation types. Many patches of the pastorally more productive land systems and vegetation types are

excluded because they occur within the degraded zone (which also extends further from water compared with the pastorally less productive grouping).

Conversely, values of the contagion index increase for both stratifications when only the non-degraded area is considered (Figure 7). This index is a combined measure of interspersion and contiguity or clumping. Higher contagion values suggest less patchiness (fewer smaller patches) and less intermixing (less isolation) – i.e. a less fragmented landscape. Again, this result is not surprising as much of the area of pastorally more productive land systems and vegetation types is excluded when the non-degraded area is analysed.

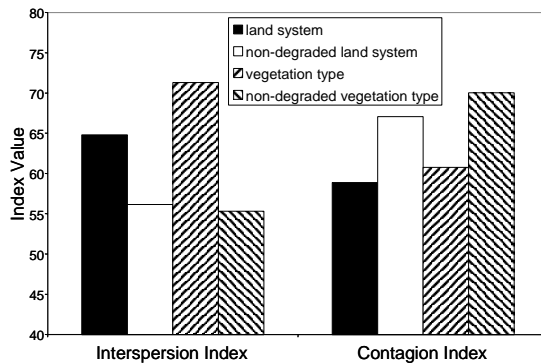


Figure 7. Interspersion and contagion index values for the entire, and non-degraded, areas of land systems and land systems grouped into vegetation types. Each column represents a single value calculated for the whole of each analysed region, rather than the mean of component land systems or vegetation types, and thus it is not appropriate to show error bars to indicate statistical differences.

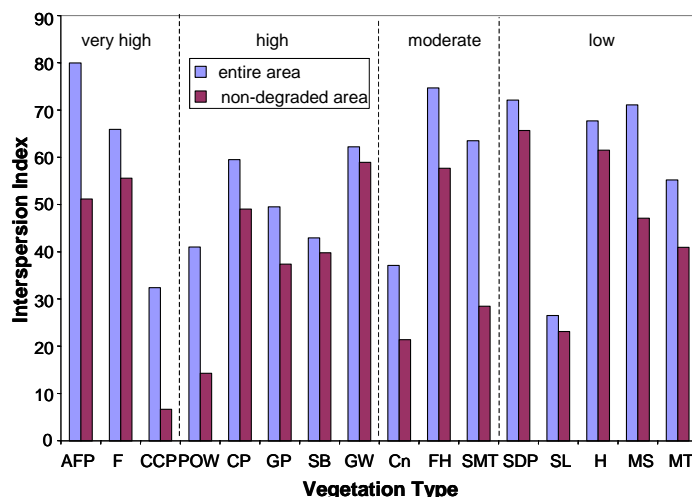
Class level (i.e. mapped area of each land system or vegetation type)

Interspersion index values are lower for the non-degraded area of all vegetation types compared with the total area (Figure 8). This reduction is generally more marked for vegetation types that are pastorally more productive compared with less productive categories. Lower values indicate reduced intermixing of patches, consistent with patches of the pastorally more important vegetation types becoming more distant and isolated on non-degraded areas compared with their total area.

A similar pattern occurs with individual land systems (data not shown). Interspersion values are lower on all but five land systems for the analysis of the non-degraded area compared with the total area. Generally, the decline is greater for the pastorally more productive land systems compared with lower productivity categories. As for the vegetation type stratification, land degradation separates patches and reduces the amount of intermixing with patches of other land systems.

Land systems where the interspersion score increases for the non-degraded area compared with the total area (Muller 1 & 2, Ringwood, Allua 3 and Kalamerta 2) appear to have considerable contiguity of non-degraded patches. This is in contrast to increased patch dispersal in the non-degraded area of land systems where interspersion declines when only the non-degraded area is considered. Contiguity of patches within the non-degraded area of a land system appears to increase the probability of those patches being adjacent to non-degraded patches of other land systems.

Contagion and interspersion values indicate that land degradation fragments or disperses intact areas of pastorally more productive land systems and vegetation types to a greater degree than pastorally less productive country. Implications of this result for persistence of biodiversity, particularly the maintenance of rare and threatened species, are explored in the next section (Component 3).



AFP = alluvial fans & plains
 F = floodouts
 CCP = cracking clay plain
 POW = plains with open woodland
 CP = calcareous slopes & plains
 GP = granitic plains
 SB = saltbush & myall
 GW = gidyea woodland
 Cn = clayey stony slopes (Chandlers ls)
 FH = foothills, footslopes & fans
 SMT = southern mulga type
 SDP = sand dunes & plains
 SL = salt lakes
 H = hills & ridges
 MS = mulga shrubland
 MT = mulga terraces

Figure 8. Interspersion index values for vegetation types analysed by total area and by non-degraded area (i.e. that area where complete recovery in wet-period vegetation cover occurs). Vegetation types are arranged by pastoral productivity category.

Component 3 – Index of Potential Threats to Biodiversity

In this section, we develop and test some simple ratios that may indicate potential threat to the maintenance of biodiversity. We test the relevance of these indices by relating them to botanical data provided by the NT Herbarium. First, we provide an overview of this database.

Rare and Threatened Plants of the southern NT

There were 17,083 plant collection records within the 87,322 km² rectangular region encompassing our analysis area. This represents an average collecting intensity of 19.6 records per 100 km². This low density demonstrates the reality of sampling biota in the extensive area of the rangelands where access is generally difficult and variation in environmental conditions means that specimens are often not present when the collector is there. Given the sparseness of data against which to validate possible indices, we present data for the vegetation-type stratification only. The aggregation of land systems into this broader stratification increases the sample size of Herbarium records within vegetation types and increases our ability to judge the potential utility of derived indices.

There were 3,524 records within the 34,498 km² area (10.2 records per 100 km²) encompassing the 16 vegetation types analysed for grazing impact and landscape geometry (Tables 2 & 4, Figure 8). These data included:

- 40 records of nationally significant species – equivalent to 0.12 records per 100 km²
- 147 records of species significant at the NT level – equivalent to 0.43 records per 100 km²
- 2 records of species significant at the southern NT level – equivalent to 0.01 records per 100 km², and
- 791 records of species with bioregional significance – equivalent to 2.29 records per 100 km².

The distribution of all records across the 16 vegetation types is shown in Figure 9. The cracking clay plain vegetation type has by far the highest density of all records (99.5 per 100 km²) with the next highest being plains with open woodland (48.9 records per 100 km²).

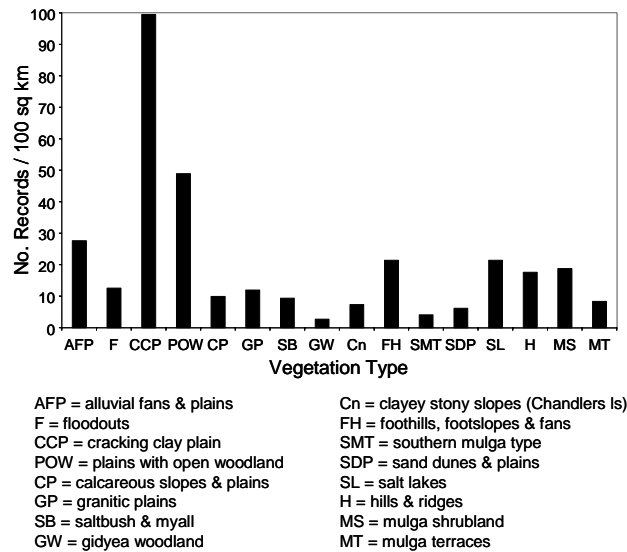


Figure 9. Density of NT Herbarium records (all species) across vegetation types. Herbarium data courtesy of Parks & Wildlife Commission of the Northern Territory.

Collecting intensity and distance from water

One of the more important factors affecting collecting intensity of plant species lodged with the NT Herbarium is access (Albrecht *et al.* 1997). Since the majority of water points in the analysis region have at least some form of track access, we tested whether areas close to water points have a higher collecting intensity than areas more distant from water.

Collecting intensity of plants with conservation significance was highest within the first one kilometre of all watering points and declined to about 14% of this value between 7 and 8 km from water (Figure 10). Despite this decline, there was still considerable collecting intensity on water-remote areas with some significant “spikes” (particularly between 20 and 21 km). There were approximately equal numbers of plant records from areas closer than 10 km to water as there were from areas further than 10 km from water. Given this spread of records, it was considered that the greater collecting intensity within 1 km of water would not significantly bias our analyses.

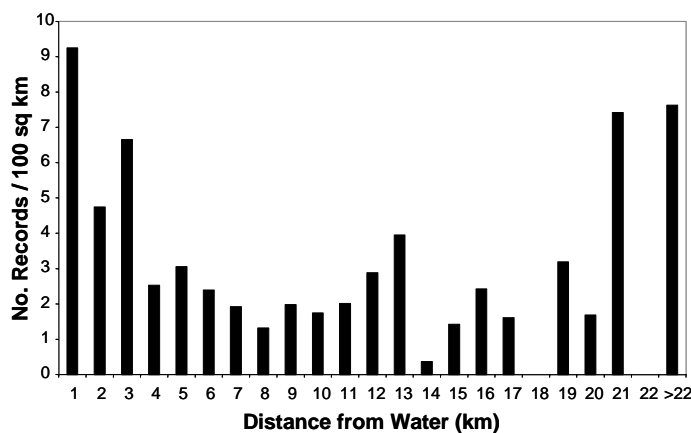


Figure 10. Density of NT Herbarium records for species with conservation significance at increasing distance from water. Herbarium data courtesy of Parks & Wildlife Commission of the Northern Territory.

Index of potential threat to biodiversity

Proportional area at distance from water

Recent research indicates that rangeland flora and fauna exhibit a range of responses to the effects of water points and the grazing they support (Landsberg *et al.* 1997, Biograze 2000). A number of species (of plants and animals) exhibit some form of “decreaser” response to a gradient from a waterpoint. At its weakest, this response can be the absence of the species within a few hundred metres of the waterpoint, but building to stable numbers from around 1 km (Figure 11). The most severe response is that a species is not found until samples are taken several kilometres from waterpoints. Species that exhibit the most severe pattern of decreaser response are likely to be intolerant of even light grazing. This group of species comprises around 5-10% of the biota in a region and we expect to find them only in water-remote locations. In this case study, we have arbitrarily defined water-remote areas as being beyond 10 km from any waterpoint. The area of each land type (in this case, vegetation type) that is further than this distance from a waterpoint, as a proportion of the total area of that land type, indicates the relative proportion of a habitat type that is minimally affected by grazing. This proportion could also indicate the potential threat to continued survival of grazing-intolerant species because of population fragmentation and isolation of sub-populations (e.g. *Vittadinia eremaea* in Figure 11). If the watered area expands, then the refuge area declines and the threat to continued survival would seemingly increase. That is, the smaller the proportional value, then (possibly) the greater the threat to continued survival of grazing-intolerant species.

Some species show a more gradual decline in their abundance as distance to water decreases. The effect of grazing on these species might be better predicted by an index that takes account of grazing impact, or land degradation, rather than an absolute distance from water (as above). We base this second index on the ratio of the area of each vegetation type that fully recovers from grazing following good rainfall to the total area of that vegetation type. The boundary between the two areas is taken as the inflexion point distance determined from grazing gradient analyses (determined in Component 1). In this case, vegetation types which have a grazing gradient persisting to a considerable distance from water following good rainfall will have a lower proportion of non degraded to total area than vegetation types where there is only minimal permanent grazing impact surrounding water. Intuitively, the threat to the continued success of grazing-affected species should be greater where the degraded area constitutes a greater proportion of the vegetation type compared with less degraded landscapes.

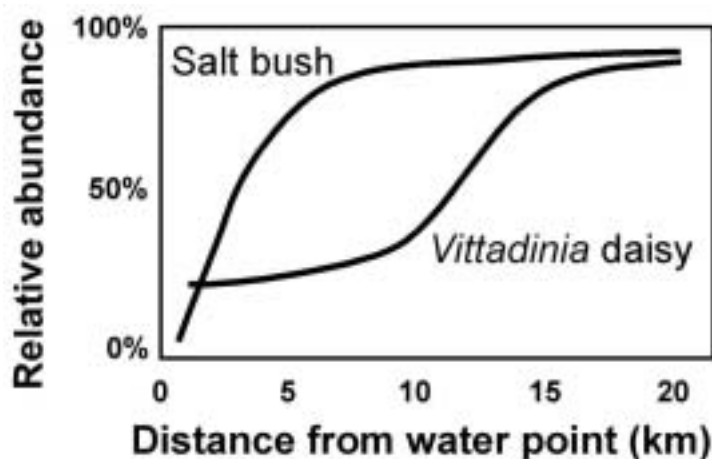


Figure 11. Examples of the extremes of “decreaser” response types. Saltbush (*Atriplex vesicaria*) is absent close to waterpoints but increases in abundance rapidly with increasing distance from the waterpoint. The Desert daisy (*Vittadinia eremaea*) is very sparse until sampled at large distances from water. (Figure reproduced from Biograze 2000.)

Ratio values, as possible indices of threat to the persistence of species, for vegetation types grouped by pastoral productivity category are graphed in Figure 12. Both ratios are scaled between 0 and 1 but the proportional area beyond 10 km from water is lower than the proportional area beyond the inflexion point for all vegetation types. Vegetation types of high pastoral productivity have low ratio values suggesting that species threatened by grazing are less secure on these areas. The proportion of total area beyond the inflexion point is generally much higher for vegetation types of lower pastoral productivity (excepting plains with open woodland and the southern mulga type). This suggests that grazing-affected species may be more secure here compared with the pastorally most productive vegetation types. Most vegetation types have less than 10% of their total area beyond 10 km from water (proportional area = 0.01) indicating limited availability of refugia for grazing-intolerant species on these landscapes. The next section tests this postulated relationship.

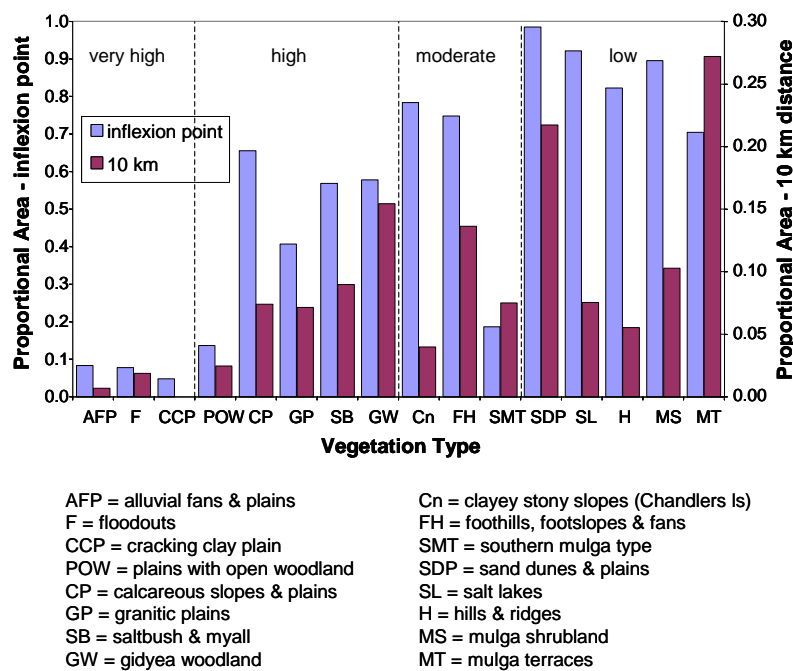


Figure 12. Ratio of (a) area of each vegetation type beyond 10 km from water divided by the total area, and (b) area beyond inflexion point (i.e. non degraded area) divided by total area as possible indices of threat to persistence of species. Vegetation types are grouped according to pastoral productivity.

Correlation of index with Herbarium records

Plant records examined are:

1. At the level of all species classified as having bioregional conservation significance (called “significant” below). There are some shortcomings with this approach because species may be included that have a restricted distribution and are rare because of local environmental conditions rather than any anthropogenic disturbing process such as waterpoints and grazing. However, given the previously described low collection density of plant species having some form of conservation status within the Herbarium records, we needed to include as many species as possible to test the robustness of indices. Where there were less than five species of bioregional significance for any vegetation type at the different distance-from-water thresholds, we excluded that vegetation type from the comparison. This meant that there were few values to compare for that area of vegetation types >10 km from water.

2. Combined for species classified as rare (i.e. at the level of “national”, “NT” and “southern NT”). This grouping is described under “rare” below. It is a separate, and smaller, dataset to that analysed under “significant”.

Both datasets contain additional records to those species currently designated as “threatened”. We have done this to increase the number of species analysed (due to the low recording density) and based on the likelihood that disturbance could pose a potential threat to persistence of many rare and/or bioregionally significant species, not just those classified as “threatened”.

We test the ability of proportional area based on the two distance-from-water criteria (Figure 12) to indicate change in biodiversity by correlating ratio values against various indices derived from the NT Herbarium records. The two distance-from-water criteria are:

- (a) that area further from water (either >10 km or beyond the inflexion point distance), and
- (b) that area closer to water (i.e. <10 km or to the inflexion point distance).

Significant species

Here, we correlate proportional area of each vegetation type for the two distance criteria, against the density of bioregionally significant species. The data compiled to compare proportional area of each vegetation type within 10 km of water with the density of bioregionally significant species for the same area are shown in Table 5.

Table 5. Data used to correlate the proportional area of vegetation types within 10 km of water with the density of bioregionally significant species within the same area.

vegetation type	total area	area<10 ^a	ratio ^b	# species	#/100 km ²
alluvial fans & plains (open woodland)	1215.1	1206.8	0.993	58	4.81
floodouts	920.8	903.7	0.981	25	2.77
cracking clay plain	54.3	54.3	1.000	10	18.43
plains with open woodland	325.0	317.0	0.975	18	5.68
calcareous slopes & plains	4487.8	4156.2	0.926	70	1.68
granitic plains - open woodland	1343.8	1247.7	0.929	24	1.92
saltbush & myall	384.5	350.1	0.910	7	2.00
gidyea woodland	1129.8	955.5	0.846	6	0.63
clayey stony slopes - Chandlers I.s.	2486.6	2387.3	0.960	38	1.59
foothills, footslopes, colluvial fans & plains	942.8	814.3	0.864	37	4.54
southern mulga type	1946.6	1800.8	0.925	9	0.50
sand dunes & plains	14901.8	11665.3	0.783	106	0.91
salt lakes	354.0	327.3	0.925	16	4.89
hills & ridges	464.8	439.1	0.945	18	4.10
mulga shrubland	3395.9	3047.0	0.897	72	2.36
mulga terraces	144.3	105.0	0.728		0.00

area<10^a area (km²) within 10 km of water
ratio^b area<10 / total area

Using our criterion of at least five species to determine a correlation, we correlate the ratio of area against species density (#/100 km², Table 5) for 15 vegetation types ($r = 0.50$, $P < 0.05$). The distribution of values in the area ratio – species density data space, and the trend line through these data, are shown in Figure 13.

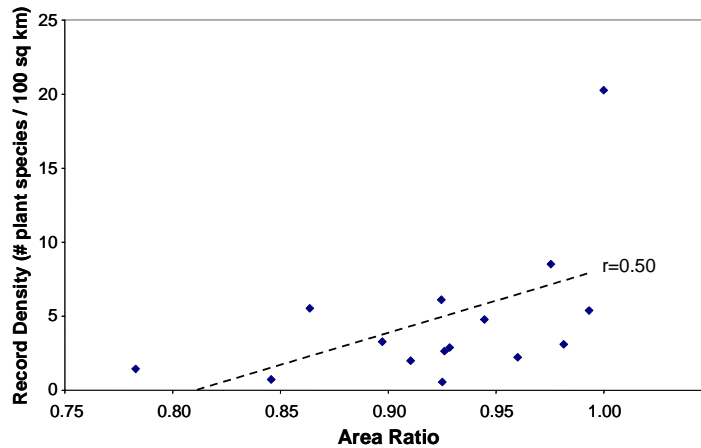


Figure 13. Scatterplot of the ratio of the area of each vegetation type within 10 km of water divided by its total area (X axis), and the density of bioregionally significant plant species (Y axis) for that vegetation type. Ratio values close to 1 indicate that the majority of the total area is within 10 km of water. There is a direct relationship between the recorded density of plant species with recognised conservation status and proportional area within 10 km of water.

Correlations derived from corresponding datasets for other distance-from-water regimes are listed in Table 6.

Table 6. Correlations between the proportional area of vegetation types at two distance thresholds from water and the density of bioregionally significant species within the corresponding area.

Distance Threshold		No. veg types	Correlation	Significance
10 km	before distance threshold	15	0.50	P<0.05
	beyond distance threshold	2	n/a	
inflexion point distance	before distance threshold	12	0.26	n.s.
	beyond distance threshold	7	0.12	n.s.

The sparseness of bioregionally significant species (either real or due to low collection intensity within the NT Herbarium records) and the relatively small available area meant that there were few data points for vegetation types beyond both distance thresholds (10 km from water and the inflexion point distance).

The number of plant species with recognised conservation status increases in direct proportion to the watered intensity (at the 10 km threshold) of each vegetation type (Figure 13). The correlation ($r = 0.50$) suggests that this relationship has some predictive value. If the persistence of some or all of these species is threatened by grazing, then the proportional area of each landscape watered to the 10 km distance is a useful indicator of potential or actual threat to the continued persistence of these species.

Our testing of available data shows a much more tenuous link between the recorded density of bioregionally significant plant species and the area of each vegetation type that is affected (or not affected) by past grazing. This lack of a demonstrated relationship could occur for a number of reasons:

- Some species of bioregional conservation status may be relatively insensitive to grazing. Examples include species of trees, shrubs and forbs that are either ungrazed or rarely grazed.
- The very low sample density of Herbarium records against which indicators are being tested. This is not intended as a criticism of those who have built the NT Herbarium record but as a reminder of the immense effort required to adequately sample flora (and fauna) in the extensive and generally remote rangelands. Additionally, the record has been compiled for several purposes, not solely in an effort to adequately sample plants of conservation significance.
- The trends identified in this study have not been recognised in the past and collecting efforts have not been formally stratified in the way developed here. This is a research area requiring future testing given the existence of the relationship demonstrated here.
- Herbarium records, as analysed, indicate the existence of species, not their persistence. Persistence would require evidence of successful recruitment and a varied age structure for the geographic distribution of species with conservation significance. This information is probably lacking for many species and, if available, is beyond the scope of this case study to collate and analyse.
- Presence of land degradation that is spatially inadequately represented by wet-period grazing gradients and the inflexion point distance. The inflexion point indicates where, on average, vegetation cover is fully restored following above-average rainfall. As such, it provides an indication only of where landscapes are either unaffected by grazing or where grazing effects persist. For any vegetation type, there may be areas closer to water that fully recover and areas beyond the inflexion point distance that show evidence of land degradation. Because the inflexion point distance does not absolutely define where land degradation exists, it cannot empirically indicate where grazing-sensitive species may be present or absent.

Rare species

We used the same proportional area data described above but this time correlated the ratio values against the number of “rare” species as a proportion of the total number of species for that vegetation type. “Rare” species included those classified at the level of “national”, “NT” and “southern NT”. Again, we tested the NT Herbarium data against our two distance criteria; 10 km from water and the inflexion point distance. Both raw, and various transforms, of the data were correlated; the strongest correlations resulting from \log_{10} conversion of both proportional area and ratio of rare species to all species within the NT Herbarium records (Table 7).

Table 7. Correlations between \log_{10} transformed proportional area of vegetation types at two distance thresholds from water and the \log_{10} transformed recording of rare species as a proportion of all plant species within the corresponding area. Rare species include those classified at the level of “national”, “NT” and “southern NT”.

Distance Threshold		No. veg types	Correlation	Significance
10 km	before distance threshold	15	-0.35	n.s.
	beyond distance threshold	6	0.16	n.s.
inflexion point distance	before distance threshold	12	0.75	P<0.01
	beyond distance threshold	12	0.65	P<0.05

The distribution of values in the area ratio – species ratio data space for that area within the inflexion point distance, and the trend line through these data, are shown in Figure 14.

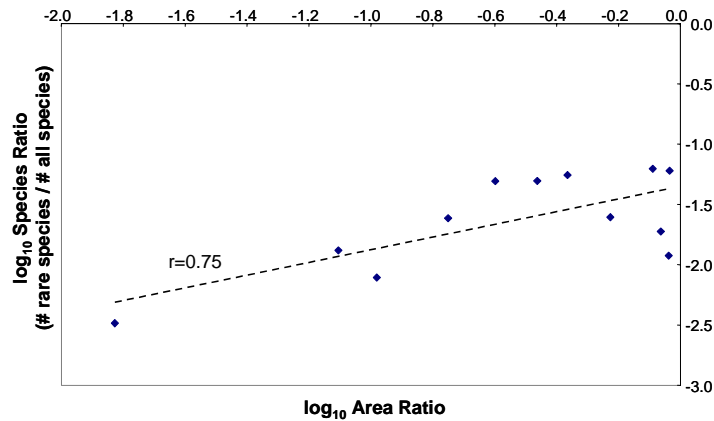


Figure 14. Scatterplot of the \log_{10} transformed ratio of vegetation type area within the inflexion point distance from water divided by total area (X axis), and the \log_{10} transformed record of rare species as a proportion of all plant species within the corresponding area (Y axis). Vegetation types with a higher proportion of degraded to total area have a higher proportion of rare species within their total species complement.

This index may have some predictive value for indicating persistence of rare species that are potentially threatened by the existence of land degradation. These species would be expected to gradually increase in abundance with distance from water as impact of grazing diminished – i.e. similar to the trend shown for saltbush in Figure 11.

Interspersion score

Interspersion scores, as a measure of landscape fragmentation, were correlated with the density of plant species with bioregional conservation significance in a similar manner to distance from water described above (results in Table 8). We used two distance-from-water thresholds with which to calculate interspersion scores:

- (a) that area of each vegetation type within and beyond 10 km of water, and
- (b) vegetation types within the inflexion point distance (i.e. showing some evidence of grazing-induced land degradation) and beyond the inflexion point distance (no land degradation).

Example values of interspersion scores are shown by the bars depicting “non-degraded area” in Figure 8.

Table 8. Correlations between interspersion scores of vegetation types at two distance thresholds from water and the density of bioregionally significant species within the corresponding area.

Distance Threshold		No. veg types	Correlation	Significance
10 km	before distance threshold	15	-0.41	n.s.
	beyond distance threshold	2	n/a	
inflexion point distance	before distance threshold	12	-0.31	n.s.
	beyond distance threshold	7	-0.25	n.s.

Interspersion scores indicating the degree of fragmentation of vegetation types at the 10 km distance show a weak (non significant) relationship with the recorded density of bioregionally significant plant species. As such, interspersion may have weak predictive value for indicating potential threat to the persistence of plant species that are intolerant of grazing. This is a similar, although less robust, result to that obtained using simple proportional areas within the 10 km distance threshold (Table 6).

Interspersion scores derived from the arrangement of vegetation types within and beyond the inflexion point distance appear inadequate for indicating potential threat to the persistence of plant species. Our failure to demonstrate a relationship may be because no simple linkage exists, or because of inadequate data, for reasons similar to those outlined above.

Assessment of indices

The limited scope of this case study indicates that a simple index based on the proportional area within or beyond 10 km of water is related to the recorded distribution of plant species, which have bioregional conservation significance. Interspersion scores measuring the degree of landscape fragmentation at the same distance threshold are weakly related to the same species dataset. As such, either index may have some value for indicating potential threat to persistence of plant species that are adversely affected by grazing.

A similar area-based ratio (i.e. area of vegetation-type that is within the inflexion point distance as a proportion of total area) was related to the proportion of rare plants in the NT Herbarium database. This index may have some predictive value for indicating persistence of rare species that are potentially threatened by land degradation.

Several caveats apply to the use of these indices, including:

1. NT Herbarium records against which all indices were validated were spatially very sparse and not collected in the stratified way that they were used in these tests.
2. Data were lacking on which species are rare or threatened because of grazing directly, or by changes to the environment brought about by grazing, or by other, non-grazing related processes.
3. Pastorally-more productive habitats may have a naturally higher proportion of species that are classified as rare or threatened. This proposition would need refuting before application of these techniques in decision making.
4. The recorded existence of species does not infer persistence. Additional information is required about levels of recruitment, age structure, and population dynamics to develop a more credible index.

This preliminary analysis does, however, suggest that there may be value in further examination and testing of patterns of distribution of rare taxa in relation to patterns of grazing and waterpoint development. Verification of these patterns in other regions and for different taxa (where data are available) may lead to the development of an index of “partial biodiversity threat” for dry rangelands. Sources other than waterpoints and grazing also lead to biotic impoverishment and these other sources will need to be considered for a more complete “biodiversity threat” index.

Component 4 - Recommendation on a whole landscape approach to using this method in the rangelands

Our analyses have been constructed on a dataset that covers an area of some 34,000 km² in central Australia. This is at a scale that we consider to be landscape in extent. These techniques could be translated to other rangeland landscapes with several notes of caution. Firstly, the method developed and tested in this case study is suitable for determining “biodiversity condition” at the landscape scale provided the term “biodiversity condition” is carefully defined and explicitly stated. Here, we intend it to mean probable change in the abundance of species (either plant or animal) known to be adversely

affected by grazing. As such, this is a rather narrow definition because it does not take into account species responses to a range of other threatening processes that operate in rangeland landscapes. Second, given the trends in species performance / persistence indicated by distance from water and grazing-induced habitat change, we recommend that our approach is applied at a broader scale (i.e. at the level of habitats, groups of similar land systems) rather than at the finer scale (of, for example, land units). We make some observations about scale of analysis in Component 6.

We acknowledge that within the constraints of this case study, our indices of potential threat to species persistence are indicative only. Their verification was particularly constrained by the lack of sufficient and suitable independent data – a recurring problem when working in the extensive rangelands. Nevertheless, our approach to developing these simple indices was underpinned by trends in species abundance established at many *Acacia* woodland, chenopod shrubland and mitchell grassland sites throughout the grazed rangelands (Landsberg *et al.* 1997, Biograze 2000). They do therefore have potential to be generalised to other similar vegetation types. Because the pattern of decrease in species' abundance with distance from water is consistent across these different types, admittedly with different sensitivities, it is likely that some proportion of the biota of most Australian rangeland ecosystems will have a “decreaser” response to grazing.

The significant correlational results between pastoral development and species status warrants further investigation. Importantly, this result provides a rationale for stratification of future collections: that is, by habitat and distance from water (or accurate spatial location). Well-stratified collection of data by all field biologists will result in the accumulation of sufficient data to verify these patterns. This solves a perennial problem in rangelands studies, which is the need for large numbers of specimen records over large areas. As an example, the Bird Atlas project incorporates distance from water as a habitat descriptor. This simple attribute collected by large numbers of people can provide a powerful set of data for the analysis of trends on spatial (and temporal) scales that defy traditional design and budgetary constraints.

Component 5 - Comments and recommended improvements to the Condition Framework as applied to a rangelands environment

Note: We were advised by ERIN (telephone conversation with Elizabeth McDonald 7/12/00) that because the Condition Framework was not available, we were not required to review it. However, we do provide the following general comments about rangeland monitoring in relation to this case study. Some of these comments may be useful in a later evaluation of the Condition Framework.

One of the difficulties in assessing (and monitoring) change in condition of the rangelands brought about by human activity is the very large area involved and the paucity of suitable ground data. This points to the potential value of satellite imagery where complete coverage of the entire area is routinely available. Unfortunately, one of the problems in analysing these data has been the lack of suitable, robust models of landscape behaviour that allow the amount of human-induced change to be quantified and interpreted against the often large natural variation that rangeland systems exhibit. This situation has recently changed with the development and application of remote sensing-based methods for monitoring grazing effect on vegetation (see, for example, Pickup *et al.* 1994, 1998; Bastin *et al.* 1998; Karfs *et al.* 2000). However, there are, as yet, no clearly established procedures for determining grazing impact on biodiversity across the extensive rangelands.

This case study has allowed us to explore remote sensing and GIS based methods as a possible means to overcoming this deficiency. Our method of determining the possible status of biodiversity in the rangelands is based on the degree of habitat change brought about by grazing. This approach, in turn, is based on the known response of many species (both plant and animal) to grazing (Landsberg *et al.* 1997). Some species are favoured by either the landscape disturbance produced by grazing or the provision of more abundant and permanent water supplies. Other grazing-sensitive species decline in proportion to the changes caused by grazing while approximately 10% of species thus far surveyed are intolerant of grazing and are now only found in undisturbed water-remote locations. There are thus two potential approaches to assessing biodiversity condition. One is the direct relationship

between proximity to water and the likely or probable fate of species adversely affected by grazing and the other is the degree of landscape fragmentation resulting from water development and grazing. With both approaches, it is useful to consider two distance thresholds: one that represents the likely abundance of grazing-intolerant species (i.e. at a further distance from water) and a second that reflects the probable abundance of grazing-sensitive species. Intuitively, this second distance should be related to the amount of habitat alteration (i.e. land degradation) caused by grazing.

There are two components to consider in regard to extending our approach to the entire rangelands. One is the relevance of our approach and the other is logistics (i.e. data requirements, analysis, interpretation and validation of the outputs). In regard to relevance:

1. Our method is based on extensive grazing in the arid and semi-arid rangelands. Thus, the predominant land use must be grazing by domestic stock or feral or native grazing animals (e.g., goats and kangaroos) that are reliant on water points for drinking during the warm to hot months of the year.
2. Paddocks should be large (tens to hundreds of km²), grazing-induced gradients of vegetation change (e.g. cover) discernible and water-remote areas available. In this case study, we have defined "water-remote" for the cattle-grazed rangelands to be further than 10 km from water. Sheep do not forage as far as cattle and a more realistic distance in the sheep-grazed rangelands would be 6 km; as a rule of thumb, this distance is also relevant to goats and kangaroos. But in sheep-grazed rangelands, the impact of grazing at a particular distance from water can break down under the following circumstances: (i) where there are large numbers of goats or kangaroos that cross fencelines so distances from water must be calculated independently of fencelines (i.e. not within paddocks); (ii) saline drinking water causes animals to return for drinks more frequently than they would have with access to fresh water and so the foraging distance from water is less (Cridland and Stafford Smith 1993); (iii) patches of highly preferred vegetation may be heavily grazed despite relatively long distances from water; and (iv) gradients are not circular around water points because sheep graze into prevailing winds (usually southeast to southwest in southern rangelands) and so the gradients are stretched out in this direction relative to the northerly direction from water.
3. Likely species response to grazing disturbance should be known, or able to be confidently predicted with reference to suitable analogue species.
4. Rabbits are independent of drinking water and their localised impact around rabbit warrens can be substantial. Although recent epidemics of calici virus have effectively lowered rabbit populations to less than 5 % of their former levels, there is likely to be lingering and future effects in habitats where they were formerly abundant.

Logistics of applying our method

Required digital data include:

1. A database showing the location of paddocks and water points. This is used to calculate the distance of every location from its nearest source of water.
2. A landscape stratification that reflects the way in which sheep or cattle graze the different vegetation communities available in each paddock. This information can come from either existing maps (provided they are of sufficient resolution; see Component 6) or suitably classified satellite data.
3. Satellite imagery processed to a suitable index of vegetation cover for dry and wet periods. The data should be of sufficient resolution to capture land degradation processes caused by grazing (CSIRO research has shown that Landsat MSS and TM data are suitable in central Australia whereas NOAA AVHRR data are not because of their coarse 1 km pixel resolution). Wet period data should be acquired after sufficient rainfall to allow vegetation to maximise its recovery from grazing effects. Dry period data are ideally acquired before this growth event (but earlier data may be substituted).

The satellite data are analysed in conjunction with distance-from-water information and the landscape stratification to identify dry and wet period grazing gradients. Where wet-period grazing gradients persist, an index of land degradation is calculated. Grazing gradient analyses are made using CSIRO-developed software. Access to this software is available by negotiation and CSIRO has compiled extensive documentation to assist in applying the method.

The index of land degradation is based on that distance from water where vegetation cover is fully restored following good rains. This distance, as a threshold, may have relevance to the persistence of species which are sensitive to grazing (although this needs to be established if the technique is extended to other rangeland areas). The distance will vary for each class of country depending on the extent to which a grazing gradient persists following good rainfall. A second, constant, distance is also selected; i.e., the distance beyond which grazing-intolerant species are known (or presumed) to persist.

Once these distance-from-water criteria are established, proportional areas are calculated using standard GIS software (e.g. ArcView). Measures of landscape geometry, particularly the interspersion index, can be calculated with FRAGSTATS or public-domain variants (e.g. LEAP II) downloadable from the world wide web. Proportional areas at the different distance-from-water criteria and the various measures of landscape geometry can then be processed to indices that may provide information about potential threat to the continued persistence of species affected by grazing. The relevance and accuracy of such indices would need to be established when this approach is extended into other rangeland regions. The likely biggest limitation in extending our approach is the lack of suitable and sufficient independent biodiversity data to verify the performance of such indices.

In summary, we consider that our approach is transferable to other parts of the grazed rangelands: remotely-sensed grazing-gradient responses showing long-term degradation can be developed for other parts of the rangelands provided that (a) grazing gradients are likely to exist (and persist following good rains) and (b) the necessary spatial and temporal (i.e. satellite) database can be compiled to quantify any land degradation. Analysis of land areas remote from waterpoints can also be done with a suitable GIS of cadastral information that most state land management agencies now have. However, the sort of biodiversity-change index attempted here for the first time, using rare and bioregionally significant species in a state herbarium database, must be explored and verified much more than was possible in this study. The biggest constraint in extending the method is the limited availability of suitable biodiversity data to validate such remote sensing-based analyses; of course, this is also a problem for any other assessment of threat in the rangelands. Focussing future collection effort on sampling stratified by indices such as those suggested here could alleviate this problem.

Component 6 - Intersect NVIS Vegetation Data with Land System Mapping

Erlunda land-unit mapping (1:100,000 scale)

Detailed land unit mapping demonstrates how land systems are composed of a recurring pattern of land units (Table 9). For example, Ebenezer land system is represented by predominantly erosional surfaces but also extends across every other geomorphic unit mapped at 1:100,000 scale on Erlunda. Lindavale is another complex land system with a large proportion of sandplain and lesser components of peneplain and erosional surfaces. The two "sand dune and plain" land systems (Simpson and Singleton) fall mainly within the "sandplains & dunes" geomorphic unit but also include small proportions of other geomorphic units.

Table 9. Intersection of mapped land systems (columns) and land units (rows) on Erldunda pastoral lease. Cell figures show the percentage of the total area (2966.8 sq km) at each intersection. Land units have been grouped into geomorphic units (see Appendix 3). Our broader grouping of land systems into vegetation types is shown above the land system headings.

geomorphic unit	calcareous plains		saltbush & myall	mulga shrubland		sand dunes & plains		salt lakes	total
	Ebenezer	Lindavale	Kalamerta 1	Kalamerta 2	Karee	Simpson	Singleton	Amadeus	
hills & rises	0.4	0.3		0.1			0.1		0.9
peneplains	3.9	4.3	0.1	3.2	0.9	0.5	1.4	0.1	14.4
erosional surfaces	11.2	2.9		0.1		1.6	0.3	0.5	16.6
sandplains & dunes	7.7	12.1	0.1	5.4	3	15.4	11.3	4.6	59.6
drainage & salt lakes	2.3	1.1		0.2		0.4	0.4	4	8.4
total	25.4	20.7	0.2	9	3.9	17.9	13.5	9.2	99.9

There is greater complexity when the correspondence between mapping scales and approaches is examined at the finest scale of land units (Table 10). Both Ebenezer and Lindavale land systems are described by more than 20 mapped land units and the most common land unit in each case represents less than a quarter of the total area of each land system. Only Karee land system is relatively uniform in that it contains five land units and the most dominant occupies 63% of its area.

Table 10. Land units within land systems on Erldunda pastoral lease. "Largest unit" is the identity of the most common land unit within the land system (see Appendix 3 for descriptions). Only land units occupying greater than 2 sq km are included within the count of number of units (i.e. No units). Areas smaller than this could result from slight misregistration errors between the different maps.

land system	Area (sq km)	No units	Largest unit	largest unit as % of l.s. area
Ebenezer	754.7	23	3.5	16
Lindavale	614.2	22	4.1	23.4
Kalamerta Two	268.0	10	4.3	37
Karee	116.5	5	4.3	63
Simpson	531.9	13	4.6	36.5
Singleton	400.9	14	4.3	32
Amadeus	272.6	14	4.6	19.5
Total	2958.72			

Land system mapping is acknowledged as representing reconnaissance-level description of the land resources (soils and vegetation) within a region. The increased commitment to air photo interpretation, ground survey and field checking should mean that land units mapped at 1:100,000 scale provide a more detailed and accurate spatial representation of soils and vegetation. However, end uses may mean that such additional detail is not always necessary or warranted. Cattle do not necessarily graze vegetation at the fine scale that it is delineated on the Erldunda land unit map but rather, move across several land units in their search for palatable forage. Habitat for different bird species may be defined by several land units which have a similar vegetation structure, whereas different ant species are found responding to the fine-scale differences in soil textures and available microclimates on different land units. End users might merge mapped land units into structured groups before conducting further analysis.

Merging at least some of the Erldunda land units prior to determining grazing impact using grazing gradient methods would be required for two reasons. Firstly, as explained above, it would be sensible to construct a broader landscape stratification that approximates the way in which cattle selectively graze in large paddocks. This should be based on known grazing preference for the predominant forage species in their different phenologies likely to be present on each land unit. Another reason for bulking land units is statistical – to increase the area analysed when calculating average cover at each distance increment from water. The confidence in separating grazing effects on the vegetation from

that due to background or inherent landscape variability increases as the number of pixels analysed at each distance from water increment increases (Bastin *et al.* 1993). These authors recommend that where the area analysed within any distance-from-water increment is less than 150 pixels, the results should be interpreted cautiously. Number of pixels analysed is a function of pixel size (i.e. data resolution), distance-from-water increment used and landscape complexity. As an example, there is less than 150 ha of Land Unit 3.6 (calcareous soil with mulga or myall and bluebush) within each of the first four 1 km distance increments from water on Erldunda. In practice, we determine average cover levels at distance increments of 200 m. A 200 m distance increment would considerably reduce the area over which cover was averaged further increasing the uncertainty in identifying grazing impact (i.e. land degradation) on this example land unit, and many others. The requirement then is to maximise, within reason, the number of pixels analysed to determine average cover. Options available for achieving this are:

- Use a smaller pixel size; this is only feasible where vegetation cover is derived from higher resolution satellite data (i.e. Landsat TM or SPOT).
- Increase the distance increment within which average cover is determined for each land unit; but this dampens any trend in average cover with distance from water because average cover is being calculated from a bigger area.
- Amalgamate pastorally-similar land units so that cover is averaged over a bigger area at each (200 m) distance increment; the preferred option where justifiable.

NT Vegetation map (1:1,000,000 scale)

Twenty four vegetation associations (Wilson *et al.* 1990) with an area of greater than 5 km² (an arbitrary threshold used to account for possible map misregistration errors) intersect the land systems analysed for land degradation and landscape geometry. The most extensive vegetation association is “*Acacia aneura* (Mulga) tall sparse-shrubland with grassland understorey” (3165.4 sq km) and the rarest is “*A. kempeana* (Witchetty Bush) *Acacia* tall open-shrubland with *Cassia*, *Eremophila* (Fuchsia) open-shrubland understorey” (38.6 sq km). (The complete list of mapped vegetation associations is provided in Appendix 4.)

Mapped vegetation associations generally occur across several land systems and vice versa (i.e. individual land systems are associated with several vegetation associations). The most diverse land systems are Simpson and Singleton (both with 18 vegetation associations), and Finke (with 14 associations). Two vegetation associations (“*A. aneura* (Mulga) tall open-shrubland with *Eragrostis eriopoda* (Woollybutt) open-grassland understorey” and “*A. aneura* (Mulga) tall sparse-shrubland with grassland understorey”) are spread across 20 land systems. Three vegetation associations occur across 16 land systems and five associations occur across 11 land systems.

Despite this diversity, there is correspondence between mapped vegetation associations and the dominant vegetation species described for land systems. We illustrate this with three examples:

1. Ringwood land system is described as “alluvial plains with gidyea over palatable annual pastures” (Appendix 1). Eighty five per cent (937.7 sq km) of this land system intersects with the “*A. georginae* (Gidyea) low open-woodland with open-grassland understorey” vegetation association.
2. Simpson land system describes spinifex-covered sand dunes. Eighty six per cent of this land system (9019 sq km) is mapped within the various vegetation associations broadly described as “*Triodia* spp. hummock grasslands”.
3. The vegetation association “*A. aneura* (Mulga) tall open-shrubland with *Eragrostis eriopoda* (Woollybutt) open-grassland understorey” occupies 87% (1082 sq km) of the Bushy Park land system which is characterised by groved mulga and less palatable perennial grasses (including woollybutt).

Both mapping approaches (regional land systems and vegetation associations) stratify country in different ways and at different mapping scales (1:250,000 compared to 1:1,000,000). Despite these

differences, there is broad correspondence between the vegetation delineated with each approach. Both mapping procedures probably provide suitable regional-scale information for determining land degradation and calculating indices of landscape geometry. However, they may produce different results when assessing changes and threats to biodiversity and this should be tested before substituting vegetation associations, as delineated by the NT Vegetation Map, for the land systems that were analysed in this case study.

References

- Albrecht, D.E., Duguid, A.W., Latz, P.K., Coulson, H. and Barritt, M.J. (1997). *Vascular plant checklist for the southern bioregions of the Northern Territory: nomenclature, distribution and conservation status*. Parks and Wildlife Commission of the Northern Territory. 211 p.
- Bastin, G.N., Pickup, G., Chewings, V.H. and Pearce, G. (1993). Land degradation assessment in central Australia using a grazing gradient method. *Rangeland Journal*, **15**, 190-216.
- Bastin, G.N., Tynan, R.W. and Chewings, V.H. (1998). Implementing satellite-based grazing gradient methods for rangeland assessment in South Australia. *Rangeland Journal*, **20**, 61-76.
- Biograze (2000). *Biograze: Waterpoints and Wildlife*. CSIRO Alice Springs. 13 p.
- Cridland, S. and Stafford Smith, D.M. (1993). Development and dissemination of design methods for rangeland paddocks which maximise animal production and minimise land degradation. Western Australian Dept. of Agriculture Miscellaneous Publication 42/93. 79 p.
- Karfs, R., Applegate, R., Fisher, R., Mullin, D., Novelly, P., Peel, L., Richardson, K. and Wallace, J. (2000). Satellite-based range monitoring in northern Australia: the Audit Rangeland Implementation Project. In *Proceedings 10th Australian Remote Sensing Conference*, Adelaide, Australia. Published on CD-ROM.
- Landsberg, J., James, C.D., Morton, S.R., Hobbs, T.J., Stol, J, Drew, A, and Tongway, H., (1997). *The Effects of Artificial Sources of Water on Rangeland Biodiversity*. Environment Australia Biodiversity Group and CSIRO Division of Wildlife and Ecology. 208 p.
- Li, H. and Reynolds, J.F. (1993). A new contagion index to quantify spatial patterns of landscapes. *Landscape Ecology*, **8**, 155-162.
- Low, W.A., Hodder, R.M. and Abel, D.E. (1978). Watering behaviour of British breed cattle in central Australia. In: *Studies of the Australian arid zone. III Water in rangelands* (Ed. K.M.W. Howes). Pp. 165-177. CSIRO, Melbourne.
- McGarigal, K. and Marks, B. (1995). *FRAGSTATS: Spatial pattern analysis program for quantifying landscape structure*. USDA Forest Service, Pacific Northwest Research Station. General Technical report. PNW-GTR-351. Portland, OR. 122 p.
- Perara, A.H., Baldwin, D.J.B. and Schnekenburger, F. (1997). *LEAP II: A landscape ecological analysis package for land use planners and managers*. Ontario Forest Research Institute Forest Research Report No. 146. Ontario, Canada. 88 p.
- Perry, R.A., Mabbutt, J.A., Litchfield, W.H., Quinlan, T., Lazarides, M., Jones, N.O., Slatyer, R.O., Stewart, G.A., Bateman, W. and Ryan, G.R. (1962). *General report on lands of the Alice Springs area, Northern Territory, 1956-57*. CSIRO Australia Land Research Series No. 6. CSIRO Melbourne. 280 p.
- Pickup, G. (1989). New land degradation survey techniques for arid Australia - problems and prospects. *Australian Rangeland Journal*, **11**, 74-82.
- Pickup, G., Bastin, G.N. and Chewings, V.H., (1994). Remote sensing-based condition assessment for non-equilibrium rangelands under large-scale commercial grazing. *Ecological Applications* **4**, 497-517.
- Pickup, G., Bastin, G.N. and Chewings, V.H. (1998). Identifying trends in land degradation in non-equilibrium rangelands. *Journal of Applied Ecology*, **35**, 365-377.

- Pickup, G., Chewings, V.H. and Nelson, D.J. (1993). Estimating changes in vegetation cover over time in arid areas from remotely sensed data. *Remote Sensing of Environment*, **43**, 243-263.
- Pickup, G. and Chewings, V.H. (1994). A grazing gradient approach to land degradation assessment in arid areas from remotely-sensed data. *International Journal of Remote Sensing*, **15**, 597-617.
- Shaw, K.A. and Bastin, G.N. (1988). *Land systems and pasture types of the southern Alice Springs District*. Northern Territory (Australia) Dept. of Primary Industry and Fisheries Technical Bulletin No. 136. 78 p.
- White, M., Albrecht, D., Duguid, A., Latz, P. and Hamilton, M. (in preparation). *Plant Species and Sites of Botanical Significance in the Southern Bioregions of the Northern Territory*. Volume 1: Significant Vascular Plants. A report to the Australian Heritage Commission from the Arid Lands Environment Centre. Arid Lands Environment Centre and the Parks & Wildlife Commission of the NT, Alice Springs, NT.
- White, M., Albrecht, D., Duguid, A., Latz, P. and Hamilton, M. (in preparation). *Plant Species and Sites of Botanical Significance in the Southern Bioregions of the Northern Territory*. Volume 2: Significant sites. A report to the Australian Heritage Commission from the Arid Lands Environment Centre. Arid Lands Environment Centre and the Parks & Wildlife Commission of the NT, Alice Springs, NT.
- Wilson, B.A., Brocklehurst, P.S., Clark, M.J. and Dickinson, K.J.M. (1990). *Vegetation survey of the Northern Territory, Australia: explanatory notes to accompany 1:1,000,000 map sheets*. Technical report No. 49. Conservation Commission of the Northern Territory, Palmerston NT.

Appendix 1. Land Systems

Land System	Code	Description (condensed from Perry <i>et al.</i> 1962 and Shaw and Bastin 1988)
Cavenagh One	Cv1	Granite hills, tors and footslopes in the far south. Scattered trees and shrubs. Sparse grasses and forbs.
Cavenagh Two	Cv2	Undulating granitic plains with mainly open woodland below Cv1.
Outounya	Ou	Broad granitic plains with open woodland in the far south
Chandlers	Cn	Mesas, low ranges and stony plains with mixed pastures (including Mitchell grass, bluebush and saltbush) through the central area.
Lilla	Ll	Broken stony plains with open mulga and annual pastures. Present in the south east
Ebenezer	Eb	Calcareous plains in the southern half. Bluebush or sparse trees (mulga and witchetty bush) and shrubs over annual pastures.
Allua One	Al1	Limestone ranges in the central eastern part of region. Mainly spinifex with small areas of more palatable pasture
Allua Two	Al2	Calcareous foothills, lower strike rises and valley floors adjacent to Al2. Open shrubland and annual pastures
Allua Three	Al3	Sandy wooded floodout and swamps of the Phillipson Creek in the central east.
Renner's	Rn	Undulating limestone country with witchetty bush and bluebush over annual pastures. Present through central portion of the region
Muller One	Mu1	Central area. Gently undulating limestone plains with witchetty bush over annual grasses.
Muller Two	Mu2	Depositional red earth plains with mulga below Muller One. Mixed annual and perennial grasses and forbs.
Endinda	Ed	Gently undulating stony and calcareous plains with annual pastures in the south.
Angas	An	Undulating sandy mulga plains in the central area. Mainly short grasses. Small areas of calcareous soil with bluebush or witchetty bush.
Kalamerta One	Kl1	Bluebush, saltbush and open myall plains in the far south. Annual grasses and forbs.
Kalamerta Two	Kl2	Sandy plains with mulga and myall adjacent to Kl1. Less palatable annual and perennial grasses.
Lindavale	Li	Mixed areas of sandy calcareous plains with mulga and stony calcareous soils with bluebush and annual pastures. Present in the south
Karee	Ka	Red earth mulga plains in the south. Generally less palatable annual and perennial grasses.
Ringwood	Ri	Alluvial plains with gidyea over palatable annual pastures in the central eastern part of the region.
Simpson	Si	Spinifex covered sand dunes throughout the region. Some areas with broad calcareous swales
Ewaninga	Ew	Undulating sandy country with irregular dunes in the central part of the region.
Singleton	Sn	Spinifex sandplain throughout the region. Small areas of annual-grass sandplain.
Finke	Fi	Sandy alluvial plains and floodouts of major rivers.
Todd	Td	Open woodland plains and floodouts of the Todd River and other major streams immediately south of the MacDonnell Ranges.
Amadeus	Aa	Salt lakes and fringing calcrete and gypseous outcrops in the south.
Bushy Park	Bu	Red earth mulga plains north of the MacDonnell Ranges. Less palatable perennial grasses.
Boen	Bo	Gently undulating red earth and lateritic plains with mulga adjacent to Bushy Park l/s.
Hamilton	Hm	Open woodland alluvial fans and plains north of the MacDonnell Ranges. Palatable short grasses and forbs amongst scattered whitewood, supplejack and other edible tree species.
Hamilton Four	Hm4	Texture contrast floodplains included in Hamilton l/s. Cottonbush and ephemeral herbage
Alcoota	Ac	Gently undulating open woodland and mulga plains north of the MacDonnell Ranges.

Appendix 2. Land systems grouped into Vegetation types

Vegetation Type	Component land systems	Description (Shaw and Bastin 1988)
hills & ridges	Bond Springs One	Mainly in the north - associated with the MacDonnell Ranges. Ridges and lower rocky foothill slopes. Bare rock and shallow stony soils. Low shrubs and sparse grasses.
	Cavenagh One	Granite hills, tors and footslopes in the far south. Scattered trees and shrubs. Sparse grasses and forbs.
	Pertnjara	Spinifex covered conglomerate hills in the north.
	Allua One	Limestone ranges in the central eastern part of region. Mainly spinifex with small areas of more palatable pasture
foothills, footslopes, colluvial fans & plains	Bond Springs Two	Below Bond Springs One. low hills and narrow undulating stony plains with mulga and witchetty bush. Mainly annual grasses and forbs with perennial grasses in watercourses.
	Gillen Two	Colluvial and alluvial fans and plains below Gillen One. Scattered mulga and ironwood over short grasses and forbs.
	Middleton Two	Low mesas and ridges, foothill fans and narrow alluvial plains adjacent to Middleton One. Scattered mulga, ironwood and whitewood over short grasses and forbs.
mulga terraces	Stokes	Gravel mulga terraces in the western central area. Spinifex and other less palatable grasses and forbs.
plains with open woodland	Alcoota	Gently undulating open woodland and mulga plains north of the MacDonnell Ranges.
	Chisholm	Groved mulga on lateritic soils in far north.
clayey stony slopes - Chandlers l.s.	Chandlers	Mesas, low ranges and stony plains with mixed pastures (including Mitchell grass, bluebush and saltbush) through the central area.
calcareous slopes & plains - bluebush & calcareous shrubby grassland	Ebenezer	Calcareous plains in the southern half. Bluebush or sparse trees (mulga and witchetty bush) and shrubs over annual pastures.
	Allua Two	Calcareous foothills, lower strike rises and valley floors adjacent to Allua Two. Open shrubland and annual pastures
	Renners	Undulating limestone country with witchetty bush and bluebush over annual pastures. Present through central portion of the region
	Muller One	Central area. Gently undulating limestone plains with witchetty bush over annual grasses.
	Endinda	Gently undulating stony and calcareous plains with annual pastures in the south.
	Lindavale	Mixed areas of sandy calcareous plains with mulga and stony calcareous soils with bluebush and annual pastures. Present in the south
granitic plains - open woodland	Cavenagh Two	Undulating granitic plains with mainly open woodland below Cavenagh One.

	Outounya	Broad granitic plains with open woodland in the far south
southern mulga type	Peebles	Far south east. Small areas of steep hill. Mainly broken and undulating plains with mulga, open woodland, saltbush and bluebush and short grasses and forbs.
	Lilla	Broken stony plains with open mulga and annual pastures. Present in the south east
	Angas	Undulating sandy mulga plains in the central area. Mainly short grasses. Small areas of calcareous soil with bluebush or witchetty bush.
saltbush & myall	Kulgera	Far south. Plains broken by strike dolerite ridges and laterite capped mesas with open woodland, saltbush and bluebush.
	Kalamerta One	Bluebush, saltbush and open myall plains in the far south. Annual grasses and forbs.
mulga shrubland	Muller Two	Depositional red earth plains with mulga below Muller One. Mixed annual and perennial grasses and forbs.
	Kalamerta Two	Sandy plains with mulga and myall adjacent to Kalamerta One. Less palatable annual and perennial grasses.
	Karee	Red earth mulga plains in the south. Generally less palatable annual and perennial grasses.
	Bushy Park	Red earth mulga plains north of the MacDonnell Ranges. Less palatable perennial grasses.
	Bushy Park Two	Broad drainage depressions amongst Bushy Park l.s.
	Boen	Gently undulating red earth and lateritic plains with mulga adjacent to Bushy Park l.s.
	Hamilton Three	Open mulga woodland on red earths
	McGrath Two	Dense mulga floodouts of large creeks.
gidyea woodland	Ringwood	Alluvial plains with gidyea over palatable annual pastures in the central eastern part of the region.
	Pulya	Undulating plains in the central east with gidyea and sparse annual pasture.
sand dunes & plains	Simpson	Spinifex covered sand dunes throughout the region. Some areas with broad calcareous swales
	Ewaninga	Undulating sandy country with irregular dunes in the central part of the region.
	Singleton	Spinifex sandplain throughout the region. Small areas of annual-grass sandplain.
cracking clay plain	Hamilton Five	Clay plains with neverfail and sparse Mitchell grass.
	Undippa	Cracking clay Mitchell grass plains in the far north.
alluvial fans & plains (open woodland)	Amulda	Sandy foothill fans and alluvial plains and mulga watercourses. Eastern central part of the region.
	Kanandra	Sandy alluvial plains in the eastern central area. Open woodland and short grasses and forbs.
	Todd	Open woodland plains and floodouts of the Todd River and other major streams immediately south of the MacDonnell Ranges.
	Deering	Alluvial plains below dissected terraces in the central western area. Scattered trees and shrubs over short grasses and forbs on texture-contrast soils.

	Hamilton One	Open woodland alluvial fans and plains north of the MacDonnell Ranges. Palatable short grasses and forbs amongst scattered whitewood, supplejack and other edible tree species.
alluvial fans & plains (cont.)	Hamilton Two	Foothill fans
floodouts	Allua Three	Sandy wooded floodout and swamps of the Phillipson Creek in the central east.
	Finke	Sandy alluvial plains and floodouts of major rivers.
	Hamilton Four	Texture contrast floodplains included in Hamilton l/s. Cottonbush and ephemeral herbage
	McGrath	Drainage lines, adjacent alluvial plains and floodouts of large creeks in the far north.
salt lakes	Amadeus	Salt lakes and fringing calcrete and gypseous outcrops in the south.

Appendix 3. Land Units mapped on Erldunda pastoral lease by NT Dept. Lands, Planning & Environment. Land units are structured by geomorphic unit.

1. HILLS AND RISES

- 1.1 Rises and hills of silcrete-capped weathered rock with shallow gravelly soil supporting sparse mulga over annual grasses.

2. PENEPLAINS

- 2.1 Undulating plains with red earth soil, calcareous at depth, supporting a northern myall and mulga woodland over copper burrs and annual grasses and forbs.
- 2.2 Gently undulating plains with red earth soils on limestone supporting an open mulga woodland (usually dead due to fire) over desert cassia, witchetty bush and annual grasses and forbs.
- 2.3 Plains with red calcareous soil supporting isolated mulga trees (usually dead due to fire) over annual grasses and forbs.
- 2.4 Gently undulating plains with shallow calcareous soil supporting witchetty bush over sparse shrubs and copper burrs.
- 2.5 Plains with calcareous red earth soil supporting mulga, dead finish and witchetty bush over bladder saltbush and annual grasses and forbs.
- 2.6 Gently sloping plains with red earth soil supporting mulga in groves over mainly annual grasses.

3. EROSIONAL SURFACES

- 3.1 Undulating plains with gravelly calcareous soil supporting open witchetty bush over annual grasses and forbs.
- 3.2 Undulating plains with gravelly calcareous soil supporting isolated witchetty bush and harlequin fuchsia bush over copper burrs and annual grasses.
- 3.3 Slopes and rises with red calcareous soil supporting isolated bluebush shrubs over annual forbs and grasses.
- 3.4 Slopes with red earth soils supporting an open mulga and witchetty bush woodland over a shrubland dominated by desert cassia and sparse annual grasses.
- 3.5 Gentle slopes with red calcareous soil supporting a southern bluebush dominated shrubland over annual grasses and forbs.
- 3.6 Gentle slopes with red calcareous soil supporting an open woodland of northern myall or mulga over a black and pearl bluebush dominated shrubland.

4. SANDPLAINS AND DUNES

- 4.1 Gently undulating plain with deep sandy soil supporting isolated mulga trees (usually dead due to fire) over woollybutt and annual grasses.
- 4.2 Gently undulating plain with sandy soils supporting sparse mulga over annual grasses, interspersed with bare claypan areas and clayey depressions supporting samphire.
- 4.3 Sandplain with deep sandy soil supporting an open woodland dominated by mulga over an open shrubland, woollybutt and annual grasses and forbs.
- 4.4 Sandplain with deep sandy red earth soil supporting mulga and witchetty bush over mixed shrubs, hard spinifex and annual grasses and forbs.
- 4.5 Gently undulating sandplain and low dunes with sandy red earth soils supporting a blue mallee and Mann range mallee woodland with patches of desert oak over hard spinifex.
- 4.6 Gently undulating sandplain and low reticulate dunes with sandy red earth soils supporting an open woodland dominated by mulga with ironwood over hard spinifex.
- 4.7 Longitudinal dunes with deep sandy soil supporting a low open woodland of mulga and witchetty bush over woollybutt and annual grasses.
- 4.8 Longitudinal dunes around the margins of the playa lakes, running parallel to the lake margin with earthy sands supporting isolated trees and shrubs over very sparse annual forbs and grasses.

5. DRAINAGE FEATURES AND SALT LAKES

- 5.1 Closed drainage depressions with an impermeable, unvegetated clay surface.
- 5.2 Drainage areas and depressions with clayey alluvial soil supporting a low samphire shrubland.
- 5.3 Gentle slopes and depressions with clayey alluvial soil supporting a low samphire shrubland and sandy hummocks with annual grasses and forbs.
- 5.4 Extensive salt lakes free of vegetation with a salt crust over brine.
- 5.5 Terraces and slopes formed on gypsum around the salt lake margins with sparse samphire, old man saltbush and sometimes bluebush over annual grasses and forbs.
- 5.6 Defined stream channels with a red gum woodland over watercourse grasses and their associated floodplain with coolabah, old man saltbush and perennial and annual grasses and forbs.
- 5.7 Broad drainage floors supporting a mixed woodland usually dominated by mulga over mixed shrubs and perennial and annual grasses and forbs.
- 5.8 Broad drainage floors with red calcareous soil supporting cotton bush over sparse annual and perennial grasses and forbs.
- 5.9 Swamps with coolabah over lignum, sparse shrubs, annual and perennial grasses and forbs.

Appendix 4. Vegetation descriptions for mapped associations of the NT Vegetation map (Wilson *et al.* 1990)

CLOSED FORESTS

- 1 Mixed species closed-forest (Monsoon vine-thicket).
- 2 *Allosyncarpia ternata* closed-forest.

EUCALYPT WITH GRASS UNDERSTOREY

Open Forests

- 3 *E. miniata* (Darwin Woolly Butt), *E. tetradonta* (Stringybark), *E. nesophila* (Melville Island Bloodwood) open-forest with *Sorghum* grassland understorey.
- 4 *E. miniata* (Darwin Woolly Butt), *E. tetradonta* (Stringybark) open-forest with *Sorghum* grassland understorey.
- 5 *E. miniata* (Darwin Woolly Butt), *E. nesophila* (Melville Island Bloodwood), *Callitris intratropica* (Cypress Pine) open-forest with open-shrubland understorey.

Woodlands

- 6 *E. tetradonta* (Stringybark), *Callitris intratropica* (Cypress Pine) woodland with *Plectrachne pungens* (Curly Spinifex) open-grassland understorey.
- 7 *E. tetradonta* (Stringybark), *Callitris intratropica* (Cypress Pine) woodland with grassland understorey.
- 8 *E. tetradonta* (Stringybark), *E. miniata* (Darwin Woolly Butt), *E. ferruginea* (Rusty Bloodwood) woodland with *Sorghum* grassland understorey.
- 9 *E. tetradonta* (Stringybark), *E. miniata* (Darwin Woolly Butt), *E. bleeseri* (Smooth-stemmed Bloodwood) woodland with *Sorghum* grassland understorey.
- 10 *E. tetradonta* (Stringybark) woodland with *Plectrachne pungens* (Curly Spinifex) open-grassland understorey.
- 11 *E. miniata* (Darwin Woolly Butt) woodland with grassland understorey.
- 12 *E. miniata* (Darwin Woolly Butt), *E. tetradonta* (Stringybark) woodland with *Plectrachne pungens* (Curly Spinifex) grassland understorey.
- 13 *E. tetradonta* (Stringybark), *E. miniata* (Darwin Woolly Butt), *E. dichromophloia* (Variable-barked Bloodwood) woodland with *Plectrachne pungens* (Curly Spinifex), *Chrysopogon fallax* (Golden Beard Grass) grassland understorey.
- 14 *E. tetradonta* (Stringybark), *E. tectifera*, (Northern Box) woodland with *Sorghum* grassland understorey.
- 15 *E. tectifera* (Northern Box), *E. latifolia* (Round-leaved Bloodwood) woodland with *Sorghum* grassland understorey.
- 16 *E. tectifera* (Northern Box), *E. terminalis* (Bloodwood) woodland with *Sehima nervosum* (White Grass), *Chrysopogon fallax* (Golden Beard Grass) grassland understorey.
- 17 *E. dichromophloia* (Variable-barked Bloodwood), *E. tetradonta* (Stringybark) woodland with grassland understorey.
- 18 *E. papuana*, (Ghost Gum), *E. polycarpa* (Long-fruited Bloodwood) woodland with grassland understorey.
- 19 *E. terminalis* (Bloodwood), *E. patellaris* (Weeping Box) woodland with grassland understorey.

Low Woodlands

- 20 *E. dichromophloia* (Variable-barked Bloodwood) low woodland with *Chrysopogon fallax* (Golden Beard Grass), *Plectrachne pungens* (Curly Spinifex) grassland understorey.
- 21 *E. tintinnans* (Salmon Gum) low woodland with *Sorghum* grassland understorey.
- 22 *E. terminalis* (Bloodwood), *E. chlorophylla* (Box) low woodland with *Sehima nervosum* (White Grass), *Chrysopogon fallax* (Golden Beard Grass) grassland understorey.
- 23 *E. pruinosa* (Silver Box) low woodland with *Eulalia aurea* (Silky Browntop), *Sehima nervosum* (White Grass) grassland understorey.

- 24 *E. microtheca* (Coolibah), *Excoecaria parvifolia* (Gutta-percha) low woodland with *Chrysopogon fallax* (Golden Beard Grass), *Dichanthium* (Bluegrass) grassland understorey.

Low Open Woodlands

- 25 *E. microtheca* (Coolibah) low open-woodland with *Eulalia aurea* (Silky Browntop), *Dichanthium* (Bluegrass) grassland understorey.
- 26 *E. microtheca* (Coolibah) low-open woodland with *Eulalia aurea* (Silky Browntop), *Astrebula* (Mitchell Grass) grassland understorey.
- 27 *E. microtheca* (Coolibah) low open-woodland with open-grassland understorey.
- 28 *E. microtheca* (Coolibah) low open-woodland with *Chenopodium auricomum* (Bluebush) sparse-shrubland understorey.

EUCALYPT WITH HUMMOCK GRASS UNDERSTOREY

Low Woodlands

- 29 *E. phoenicea* (Scarlet Gum) low woodland with *Plectrachne pungens* (Curly Spinifex) hummock grassland understorey.

Open Woodlands

- 30 *E. gongylocarpa* (Marble Gum) open-woodland with open-hummock grassland understorey.

Low Open Woodlands

- 31 *E. dichromophloia* (Variable-barked Bloodwood), *E. tetradonta* (Stringybark) low open-woodland with *Plectrachne pungens* (Curly Spinifex) open-hummock grassland understorey.
- 32 *E. dichromophloia* (Variable-barked Bloodwood), *E. miniata* (Darwin Woolly Butt) low open-woodland with *Plectrachne pungens* (Curly Spinifex) open-hummock grassland understorey.
- 33 *E. dichromophloia* (Variable-barked Bloodwood) low open-woodland with *Plectrachne pungens* (Curly Spinifex) open-hummock grassland understorey.
- 34 *E. dichromophloia* (Variable-barked Bloodwood) low open-woodland with *Triodia pungens* (Soft Spinifex) hummock grassland understorey.
- 35 *E. leucophloia* (Snappy Gum) low open-woodland with *Plectrachne pungens* (Curly Spinifex) hummock grassland understorey.
- 36 *E. leucophloia* (Snappy Gum) low open-woodland with *Triodia pungens* (Soft Spinifex), *Plectrachne pungens* (Curly Spinifex) open-hummock grassland understorey.
- 37 *E. brevifolia* (Snappy Gum) low open-woodland with *Plectrachne pungens* (Curly Spinifex) hummock grassland understorey.
- 38 *E. brevifolia* (Snappy Gum) low open-woodland with *Triodia pungens* (Soft Spinifex) hummock grassland understorey.
- 39 *E. pruinosa* (Silver Box), *Lysiphyllum cunninghamii* (Bauhinia) low open-woodland with hummock/tussock grassland understorey.
- 40 *E. ferruginea* (Rusty Bloodwood) low open-woodland or *Jacksonia odontocarpa* open-shrubland with *Plectrachne pungens* (Curly Spinifex) open-hummock grassland understorey.
- 41 *E. opaca* (Bloodwood) low open-woodland with *Plectrachne pungens* (Curly Spinifex) hummock grassland understorey.
- 42 *E. opaca* (Bloodwood) low open-woodland with *Triodia pungens* (Soft Spinifex) hummock grassland understorey.
- 43 *Eucalyptus* low open-woodland and/or *Acacia* sparse-shrubland with *Triodia spicata* (Spike Flower Spinifex), *Triodia pungens* (Soft Spinifex) hummock grassland understorey.

MIXED SPECIES LOW OPEN-WOODLANDS WITH GRASS UNDERSTOREY

- 44 Terminalia arostrata (Nutwood) low open-woodland with Chrysopogon fallax (Golden Beard Grass), Dichanthium (Bluegrass) grassland understorey.
- 45 Lysiphyllum cunninghamii (Bauhinia), E. pruinosa (Silver Box) low open-woodland with Eulalia aurea (Silky Browntop), Sehima nervosum (White Grass) grassland understorey.
- 46 Lysiphyllum cunninghamii (Bauhinia), mixed species low open-woodland with Sehima nervosum (White Grass), Chrysopogon fallax (Golden Beard Grass) open-grassland understorey.

MISCELLANEOUS SHRUBLANDS

- 47 Acacia open-shrubland with Sorghum grassland understorey.
- 48 Livistona humilis (Fan Palm) tall open-shrubland with Sorghum grassland understorey.

MELALEUCA FOREST TO WOODLANDS

- 49 Melaleuca citrolens (Paperbark) low woodland with Chrysopogon fallax (Golden Beard Grass) open-grassland understorey.
- 50 Melaleuca minutifolia (Paperbark) low woodland with Sorghum grassland understorey.
- 51 Melaleuca viridiflora (Broad Leaved Paperbark), Eucalyptus low open-woodland with Chrysopogon fallax (Golden Beard Grass) grassland understorey.
- 52 Melaleuca glomerata (Inland Teatree) open-shrubland.

FLOODPLAINS

- 53 Melaleuca forest (Paperbark Swamp).
- 54 Mixed closed-grassland/sedgeland (Seasonal Floodplain).

ACACIA WITH GRASS UNDERSTOREY

- A. shirleyi (Lancewood)
- 55 A. shirleyi (Lancewood) open-forest with open-grassland understorey.
- 56 Complex of A. shirleyi (Lancewood) low-woodland mixed with Eucalyptus low open-woodland.
- 57 Macropteranthes kekwickii (Bullwaddy) tall shrubland with open-grassland understorey.

Mixed Species Low Open Woodlands

- 58 A. aneura (Mulga)/mixed species low open-woodland with open-grassland understorey.
- 59 A. estropholata (Ironwood), Atalaya hemiglauca (Whitewood) low open-woodland with open-grassland understorey.
- 60 A. aneura (Mulga), Hakea (Needlewood) low open-woodland with herb/grassland understorey.
- 61 Complex of mixed species low open-woodland between dunes with Zygochloa paradoxa (Sandhill Cane Grass) open-hummock grassland on dune crests.

A. georginae (Gidyea) Low Open Woodlands

- 62 A. georginae (Giddier) low open-woodland with Astrebla pectinata (Bull Mitchell Grass) open-grassland understorey.
- 63 A. georginae (Gidyea) low open-woodland with open-grassland understorey.
- 64 A. georginae (Gidyea) low open-woodland with herbland understorey.

Tall Open Shrublands

- 65 A. aneura (Mulga) tall open-shrubland with Eragrostis eriopoda (Woolybutt) open-grassland understorey.
- 66 A. aneura (Mulga) tall open-shrubland with Cassia, Eremophila (Fuchsia) open-shrubland understorey.

- 67 A. ammobia tall open-shrubland with sparse-grassland understorey.
 68 A. kempeana (Witchetty Bush) Acacia tall open-shrubland with Cassia, Eremophila (Fuchsia) open-shrubland understorey.

Sparse Shrublands

- 69 A. aneura (Mulga) tall sparse-shrubland with Aristida contorta (Bunched Kerosene Grass) or Triodia open-tussock/hummock grassland understorey.
 70 A. aneura (Mulga) tall sparse-shrubland with Cassia, Eremophila (Fuchsia) low sparse-shrubland understorey.
 71 A. aneura (Mulga) tall sparse-shrubland with grassland understorey.
 72 A. kempeana (Witchetty Bush) sparse-shrubland to tall sparse-shrubland with grassland understorey.
 73 A. tetragonophylla (Dead Finish), A. kempeana (Witchetty Bush) sparse-shrubland with herb/grassland understorey.
 74 A. stowardii (Bastard Mulga), Cassia, Eremophila (Fuchsia) sparse-shrubland.

HUMMOCK GRASSLANDS

Tall Shrublands

- 75 Triodia pungens (Soft Spinifex) hummock grassland understorey with A. lysiphloia (Turpentine) tall open-shrubland overstorey.
 76 Triodia pungens (Soft Spinifex), Plectrachne schinzii (Curly Spinifex) hummock grassland with Acacia tall sparse-shrubland overstorey.
 77 Triodia pungens (Soft Spinifex), Plectrachne schinzii (Curly Spinifex), hummock grassland with Acacia tall sparse-shrubland overstorey between dunes.
 78 Triodia spicata (Spike Flowered Spinifex) hummock grassland with Grevillea wickhamii (Holly Grevillea), Acacia sparse-shrubland overstorey.
 79 Plectrachne melvillei (Spinifex) hummock grassland with A. aneura (Mulga), A. kempeana (Witchetty Bush) tall open-shrubland overstorey.
 80 Triodia longiceps (Grey Spinifex) hummock grassland with Acacia tall open-shrubland overstorey.
 81 Triodia basedowii (Hard Spinifex) hummock grassland with Acacia tall sparse-shrubland overstorey.
 82 Triodia basedowii hummock grassland with A. aneura (Mulga) tall sparse-shrubland overstorey between dunes.
 83 Triodia basedowii (Hard Spinifex) or Triodia pungens (Soft Spinifex) hummock grassland with E. gamophylla (Blue Mallee), Acacia tall sparse-shrubland overstorey.
 84 Triodia basedowii (Hard Spinifex) hummock grassland with E. gamophylla (Blue Mallee) tall sparse-shrubland overstorey.
 85 Triodia basedowii (Hard Spinifex) hummock grassland with Acacia tall sparse shrubland overstorey between dunes and Zygochloa paradoxa (Sandhill Cane Grass) open-hummock grassland on dune crests.
 86 Triodia pungens (Soft Spinifex) or Triodia basedowii (Hard Spinifex) hummock grassland with Acacia tall sparse-shrubland overstorey between dunes
 87 Triodia (Spinifex) open-hummock grassland with A. aneura tall sparse-shrubland overstorey.

Scattered Shrubs

- 88 Triodia (Spinifex) hummock grassland.
 89 Triodia pungens (Soft Spinifex) open-hummock grassland with scattered shrubs.
 90 Triodia irritans (Porcupine Grass) open-hummock grassland.

Mixed Species Low Open Woodlands

- 91 Triodia wiseana (Limestone Spinifex) hummock grassland with Terminalia arostrata (Nutwood) low open-woodland overstorey.

- 92 *Triodia clelandii* (Weeping Spinifex) hummock grassland with mixed species low open-woodland overstorey.
- 93 *Triodia basedowii* (Hard Spinifex) hummock grassland with *Allocasuarina decaisneana* (Desert Oak) open-woodland overstorey between dunes.
- 94 *Triodia basedowii* (Hard Spinifex) hummock grassland with *Allocasuarina decaisneana* (Desert Oak) low open-woodland or *Acacia* tall sparse-shrubland overstorey.

GRASSLANDS

- 95 Mixed species sparse-grassland or herbland.
- 96 *Astrebla pectinata* (Barley Mitchell grass) grassland.
- 97 *Astrebla* (Mitchell Grass), mixed species grassland with scattered trees and shrubs.
- 98 *Chrysopogon fallax* (Golden Beard Grass), *Dichanthium fecundum* (Bluegrass) grassland.
- 99 *Enneapogon purpurascens* (Nine Awn Grass) grassland.
- 100 *Eragrostis xerophila* (Neverfail) open-grassland with scattered trees and shrubs.
- 101 Seasonal grassland with *Muehlenbeckia cunninghamii* (Lignum) low sparse-shrubland overstorey.

LITTORAL

- 102 Coastal dune complex.
- 103 *Vetiveria elongata* grassland.
- 104 *Xerochloa* (Rice Grass) grassland.
- 105 Mangal low closed-forest (Mangroves).
- 106 Saline tidal flats with scattered chenopod low shrubland (Samphire).

CHENOPOD LOW SPARSE-SHRUB/FORBLANDS

- 107 *Chenopodium auricomum* (Bluebush) low open-shrubland with ephemeral grassland understorey.
- 108 *Maireana astrotricha* (Southern Bluebush) low open-shrubland with ephemeral open-herb/grassland.
- 109 Chenopod open-herbland with ephemeral open-herb/grassland.
- 110 *Atriplex vesicaria* (Bladder Saltbush) low sparse-shrubland with ephemeral open-herb/grassland.
- 111 *Halosarcia* (Samphire) low open-shrubland fringing bare salt pans.
- 112 Bare salt pan.