

DESERT KNOWLEDGE CRC

Wind erosion risk management for
more environmentally sustainable
primary production

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2009



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The Desert Knowledge Cooperative Research Centre is an unincorporated joint venture with 28 partners whose mission is to develop and disseminate an understanding of sustainable living in remote desert environments, deliver enduring regional economies and livelihoods based on Desert Knowledge, and create the networks to market this knowledge in other desert lands.

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We thank the many DustWatchers and community groups for their cooperation with this project. Thanks to Dr Shao for his generous cooperation in allowing us to develop the research capacity to run the IWEMS wind erosion model in Australia, and to Kenn Tews for assistance with data analysis.

Abbreviations/Acronyms

ACRIS	Australian Centre for Rangeland Information Systems
AGO	Australian Greenhouse Office
ALT	Aboriginal Land Trust
ANZECC	Australia and New Zealand Environment Conservation Council
APLC	Australian Plague Locust Commission
ASISTM	Australian School Innovation in Science Technology and Mathematics
AUSLEM	Australian Land Erodibility Model
BoM	Bureau of Meteorology
CEMSYS	Computational Environmental Management System
DEDB	Dust Event Database
DEEWR	(then) Department of Education, Employment and Workplace Relations
DEH	Department of the Environment and Heritage
DEST	(then) Department of Education Science and Training
DSF	Dust Storm Frequency
DSI	Dust Storm Index
DVC	Dust Visibility Concentration
DVR	Dust Visibility Reduction
EMS	Environment Management System
HVS	High Volume Air Sampler
IKBS	Intelligent Knowledge-Based System
IWEMS	Integrated Wind Erosion Management System
LCI	Land Condition Indicator
LDE	Local Dust Event
LMDCMA	Lower Murray–Darling Catchment Management Area
MD	Moderate Dust Storm
MSS	Multi-Spectral Scanner
NCST	National Committee for Soil and Terrain
NDVI	Normalised Difference Vegetation Index
NLWRA	National Land and Water Audit
SD	Severe Dust Storm
TM	Thematic Mapper
WEAM	Wind Erosion Assessment Model

Executive summary

The main aim of this project was to raise awareness of the soil degrading effects of accelerated wind erosion and to provide tools with the potential to increase land productivity sustainably and reduce some of the environmental uncertainties of pastoral production in the Australian desert.

The project outputs include:

1. A representative and well-connected group of research user stakeholders
2. A fully functioning DustWatch wind erosion monitoring network
3. Maps of wind erosion activity produced from: meteorological records of dust storm occurrence, a numerical wind erosion assessment model and an intelligent knowledge-based system model
4. Prototype methodologies for: quantitatively discriminating accelerated wind erosion rates, and soil condition indicators for use in property-based Environment Management Systems (EMS).

1. Research user stakeholders

A large network of research user stakeholders was established, including seven public sector organisations and seven within the private sector. Scores of new research contacts were also made through the DustWatch network and widespread community engagement was achieved through media interviews on DustWatch.

2. The DustWatch wind erosion monitoring network

DustWatch is a network of volunteer wind erosion observation sites across arid Australia which was set up to improve the accuracy of reporting of wind erosion by accessing local information (e.g. formal observations and pictures). When these observations are added to the formal meteorological record of dust activity held in the Dust Event Database at Griffith University, they provide data for the most detailed maps of wind erosion yet available in Australia and will contribute to a dust storm forecasting service. The DustWatch concept has now been extended to School DustWatch, which involves Aboriginal school children as DustWatchers in six northern Territory schools.

3. Maps of wind erosion activity

Mapping wind erosion is technically demanding because high spatial resolution maps are needed for the continent over long periods of time. Maps of wind erosion have therefore been produced from:

1. meteorological records of dust storm occurrence
2. a numerical wind erosion model called the Integrated Wind Erosion Management System (IWEMS)
3. an intelligent knowledge-based system model for describing land erodibility to wind.

Mapping of wind erosion using meteorological records has been a major long-term research focus of McTainsh and colleagues, and in the current project significant advances in mapping techniques were achieved. An improved Dust Storm Index (DSI) was developed using independent visibility data to classify erosion event types to overcome deficiencies in the Bureau of Meteorology record. The DSI was successfully tested against independent field-based dust concentration data collected in the Lower Murray Darling Catchment Management Area (LMD CMA) in New South Wales. New data

confidence maps were produced to deal with the problem of variations in the meteorological observation frequencies at different stations. New methods of dust concentration mapping were developed for high resolution mapping on an erosion event basis.

The Integrated Wind Erosion Management System (IWEMS) model of Lu and Shao (2001) (recently renamed the Computational Environmental Management System [CEMSYS]) was successfully tested on an erosion event basis for the 22–24 October 2002 dust storm (Shao et al. 2007) and for broadscale regional mapping in the LMD CMA. Agreement was also reached with the CEMSYS model developer, Professor Yaping Shao (City University of Hong Kong) to run CEMSYS in Australia on a regular basis with the cooperation of Dr Harry Butler (University of Southern Queensland).

The Australian Land Erodibility Model (AUSLEM) is being developed as part of the current project by Nicholas Webb (PhD student at University of Queensland, supervised by McGowan, McTainsh and Leys). The basic structure of the model has been developed, input data sets established and initial maps produced (Webb et al. 2006).

4. Prototype methodologies for discriminating accelerated wind erosion and for soil condition indicators for use in property-based Environment Management Systems (EMS)

Three approaches were investigated to quantitatively discriminate the component of wind erosion rates that has been accelerated by land use, using:

1. meteorological records of wind erosion
2. CEMSYS wind erosion model
3. remote sensing of vegetation.

The outcome of this development work is that each of the three approaches have merit and are worth pursuing further.

The meteorological data approach involved standardising wind erosion rates for climate (in the first instance, rainfall) by producing rainfall-adjusted wind erosion rates. The wind erosion record (1960–2004) in central Australia was then analysed using rainfall-adjusted erosion rates (i.e. erosion rate [measured by the DSI] per 10 mm of rainfall) and compared with those for eastern Australia. During 1960–1965 rainfall-adjusted wind erosion rates in central Australia were 5.6 times higher than in eastern Australia, indicating land use impacts, whereas from 1966 onwards the rates were very similar in eastern and central Australia. This result is supported by the well-documented record of accelerated wind erosion in the area around the Alice Springs airport in the early 1960s, which was largely brought under control by the introduction of buffel grass in the mid-1960s.

Wind erosion, as predicted by CEMSYS is the sum of the ‘natural’ wind erosion factors: the weather, soil conditions and vegetation cover, plus the erosion caused by land use. Model testing established that by firstly modelling the erosion rates for an area with optimal vegetation cover (e.g. as for a National Park) then re-running the model with actual cover, the differences between the two erosion rates would be the accelerated wind erosion rate.

The CSIRO contribution to the current project involved testing the efficacy of a remote sensing-based land condition index (LCI) as a possible component of an environmental management system (EMS) for the pastoral industry. There has been recent interest by pastoralists in parts of the rangelands in promoting their enterprises as ‘clean’ and ‘green’, that is, wool and/or beef produced chemical-free with grazing management benign to the environment. Although not yet formally established, it is generally considered that some form of accreditation or certification through an environmental management system (EMS) will be required to support such claims. The large size of most properties and the considerable climatic variability of the arid zone (‘deserts’) means that any EMS will need to be low

cost, efficient and, most importantly, robust in its ability to effectively separate management effects on the soil and vegetation resource from those due to natural causes (mainly rainfall and landscape variability).

The remote sensing-based land condition index (LCI) is based on paddock-level variation in vegetation cover compared with the regional average for an area of greater than 150,000 km² in the southern half of the Northern Territory. In particular, seasonal cover levels at two distance-from-water classes in larger paddocks were compared with the regional average. It is likely that enlarged areas of significantly reduced cover contribute to enhanced dust generation, particularly in drier years. Maps were produced showing where cover levels differed substantially from the average. An objective of ongoing research is to demonstrate direct correlations between local variations in historical cover and observed dust.

Introduction

Project overview

The main aim of this project was to raise awareness of the soil degrading effects of accelerated wind erosion and to provide tools that have the potential to increase land productivity sustainably, and reduce some of the environmental uncertainties of pastoral production in the Australian desert.

The project had two phases. Phase 1 involved setting up stakeholder networks and databases. Phase 2 involved developing prototypes of methodologies which will be tested and implemented.

Project outputs

The expected project outputs were to include:

1. A representative and well-connected group of research user stakeholders
2. A fully functioning DustWatch wind erosion monitoring network
3. Maps of wind erosion activity produced from: meteorological records of dust storm occurrence, a numerical wind erosion assessment model (WEAM), and an Intelligent Knowledge-Based System (IKBS) model
4. Prototype methodologies for: quantitatively discriminating accelerated wind erosion rates, and soil condition indicators for use on property-based Environment Management Systems (EMS).

The outputs of the project are summarised under these sub-headings.

1. A representative and well-connected group of research user stakeholders

The development of a broad-based group of research user stakeholders has been a significant outcome of the project. In all aspects of the project new relationships have been established with stakeholders, and/or established relationships have been developed further. A sample of new stakeholders is provided here and others will be referred to in the later sections of the report. In the public sector these include: the Bureau of Meteorology (BoM), the then Department of the Environment and Heritage (DEH), the then Department of Education Science and Training (DEST), the Productivity Commission, the National Land and Water Audit (NLWRA), the Australian Plague Locust Commission (APLC), and the Australian Centre for Rangeland Information Systems (ACRIS).

An indication of the level of engagement with the Bureau of Meteorology is that they have allocated a BoM representative to liaise directly with DustWatch. The engagement of DEST is via a research grant to extend the DustWatch concept to remote schools in the Northern Territory (see Section 2 below). The Productivity Commission has engaged the research team to provide wind erosion maps for a national survey of environmental constraints on primary production. NLWRA has appointed McTainsh and Leys to the Wind Erosion Expert Panel of the National Committee for Soil and Terrain (NCST) with the brief to develop formal indicators of soil condition in relation to wind erosion, and has approved several of the methods described in this report for demonstration trials. The APLC is an active institutional DustWatcher, and ACRIS has commissioned McTainsh and Leys to provide wind erosion maps, plus bio-region-based statistics for the rangelands for the period 1992–2005.

In the private sector, we established research user relationships with: The Bush Heritage Fund, Newmont Mining, Low Ecological Services, Northern Territory Airports (Alice Springs Airport), Arkaroola Resort and Wilderness Sanctuary, Oasis Desert Adventures, and Australian Geographic. In the broader community, we made a large number of new contacts through the DustWatch network (see Section 2 below), and we achieved widespread community engagement via numerous media interviews on the DustWatch program (see Section 2 below).

2. DustWatch: a wind erosion monitoring network

DustWatch is a network of wind erosion observation sites run by volunteers across arid Australia (Figure 1). The aim of the project was to make wind erosion reporting more accurate by accessing local information (e.g. formal observations and pictures) directly from people living in arid regions. These observations will provide data for the most detailed maps of wind erosion yet available in Australia and will contribute to a dust storm forecasting service. DustWatch membership is also contributing to a better informed desert community. Information on DustWatch can be found at the website www.griffith.edu.au/dustwatch and we have recently registered a DustWatch internet domain name.

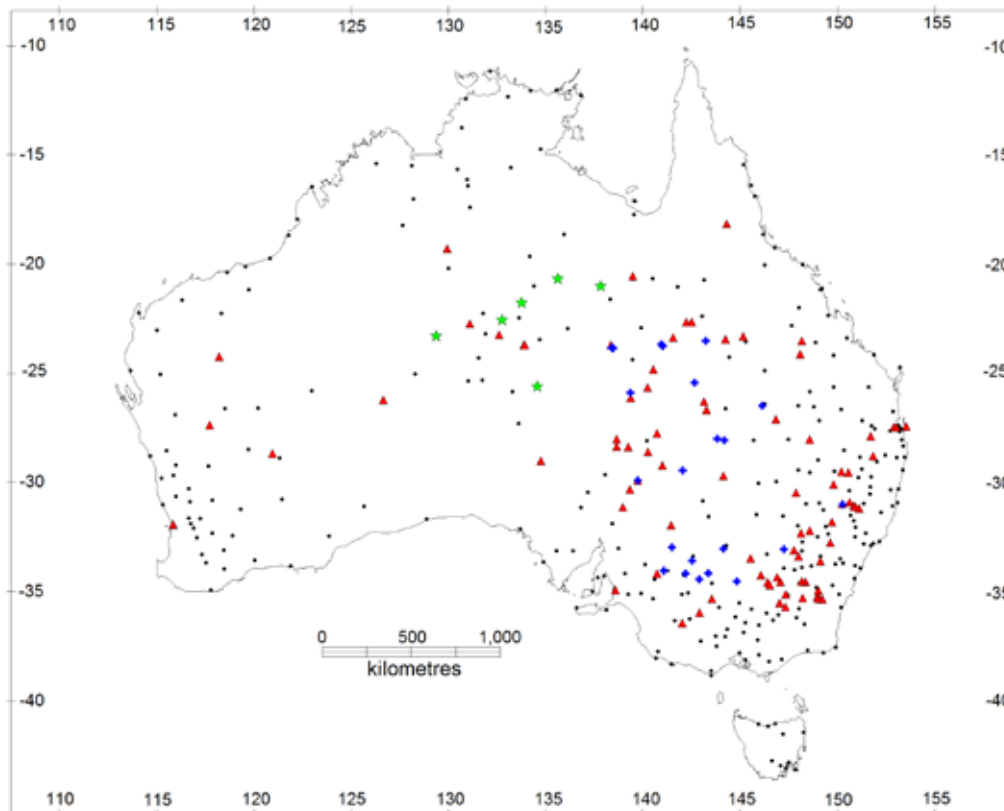


Figure 1: BoM stations (black dots), DustWatch sites (red triangles), School DustWatch sites (green stars), and DustWatch Nodes (blue crosses).

There are currently more than 100 DustWatchers from a range of sectors in the community (Figure 2).

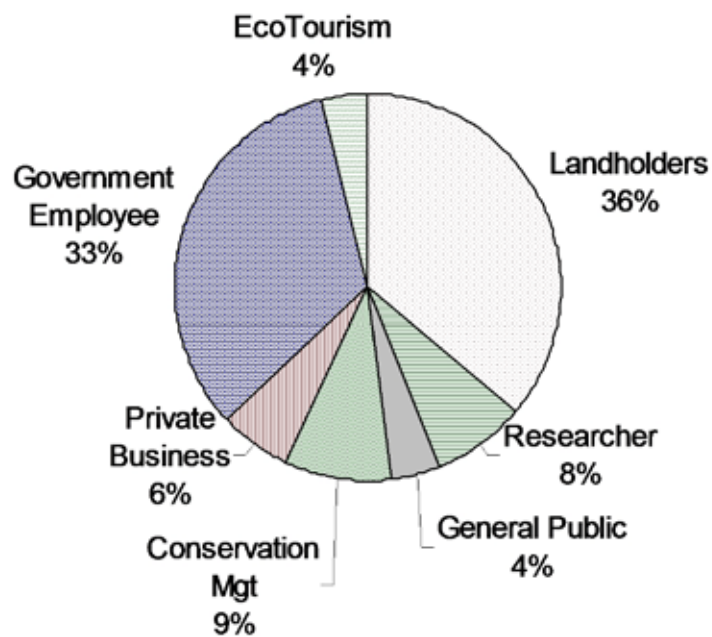


Figure 2: DustWatch membership by observer category

The distribution of DustWatch membership across the states is quite uneven at present. The predominance of DustWatchers in NSW reflects the origins of DustWatch in a pilot project in that state.

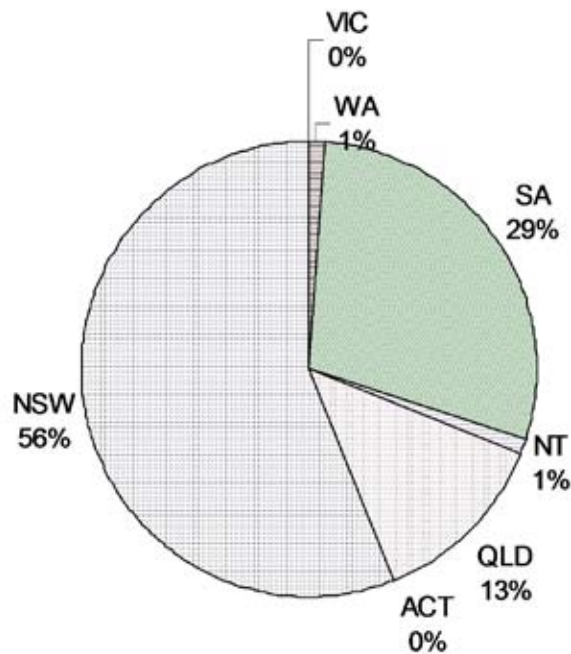


Figure 3: DustWatch membership by state

The DustWatch program successfully attracted media attention, with >25 radio interviews and >55 newspaper articles on DustWatch, and Leys has presented the outcomes of the DustWatch program at two conferences (Leys et al. 2005, 2006). We have focussed for this stage of the program on recruiting members. In the next stage we will focus on developing an improved DustWatch database to provide more frequent feedback to DustWatchers and to the wider community on dust storm events. We have in-principle agreement with the National Landcare Program to fund this phase of the project.

We have extended the DustWatch concept in a new project called School DustWatch which is funded by the DEEWR ASISTM (Australian School Innovation in Science Technology and Mathematics) Program, the Desert Knowledge CRC, and Newmont Mining. School DustWatch will involve Aboriginal school children as DustWatchers, which will allow wind erosion monitoring in remote areas where there are few pastoral properties. The School DustWatch pilot project will test the concept in six Aboriginal schools in the Alice Springs region of the Northern Territory.

3. Maps of wind erosion activity

We have produced maps of wind erosion activity from:

1. meteorological records of dust storm occurrence
2. a numerical wind erosion model called the Integrated Wind Erosion Management System (IWEMS)
3. an Intelligent Knowledge-Based System (IKBS) model.

3.1 Meteorological records of dust storm occurrence

A major research focus of McTainsh and colleagues has been mapping of wind erosion using meteorological records, and in this project, requests for annual wind erosion mapping services have come from the Productivity Commission, the *National State of the Environment Report* (McTainsh et al. 2006e), and the Australian Collaborative Rangeland Information System (ACRIS). We have also made significant advances in wind erosion mapping techniques through:

1. An improved Dust Storm Index (DSI)
2. A method for quantitative testing of different measures of wind erosion rates
3. Production of data confidence maps that can deal with the problem of variations in the meteorological observation frequencies at different stations
4. New methods for high resolution mapping on an event basis.

3.1.1 An improved Dust Storm Index (DSI)

The DSI is used for wind erosion mapping and is calculated using the following equation:

Where:
$$DSI = \sum_{i=1}^n [(5 \times SD) + MD + (0.05 \times LDE)]_i$$

DSI = Dust Storm Index at n stations, where i is the i^{th} value of n stations for $i=1$ to n. The number of stations (n) is the total number of stations recording a dust event in each year.

SD = Severe dust storm (daily maximum weather codes: 33, 34, 35)

MD = Moderate dust storm (daily maximum weather codes: 09, 30, 31, 32 and 98)

LDE = Local dust event (daily maximum weather codes: 07 and 08)

The Bureau of Meteorology (BoM) definition of a severe dust storm (SD) is when *dust is raised into the air reducing visibility to less than 200 metres*, and a moderate dust storm (MD) is when *visibility is less than 1000 metres*. A frequency analysis of all the BoM dust storm visibility records (Figure 4) shows that meteorological observers have clear preferences for ‘round numbers’ (e.g. they preferentially use 200 m, 500 m, 1000 m and 2000 m, etc).

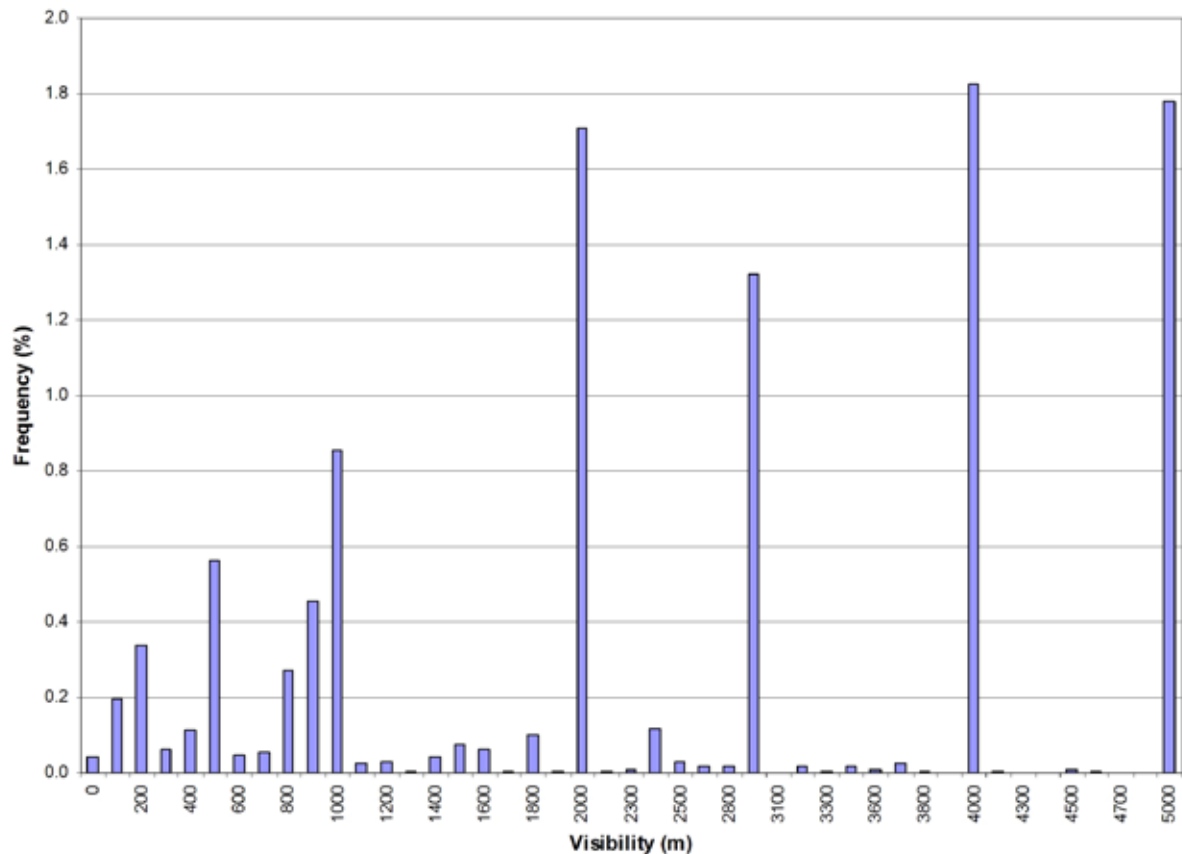


Figure 4: Frequency plot of visibility observations in the Dust Event Database 1960–2004

Meeting this observer preference for round numbers has resulted in significant under-recording of dust storms, because, according to the BoM definitions, the 200m visibility events are not coded as severe dust storms and the 1000m visibility events are not coded as moderate dust storms. To overcome this problem, the following new definitions have been introduced: *a moderate dust storm is when dust is raised into the air reducing visibility to **1000 metres or less** and a severe dust storm is when visibility is **200 metres or less***. Including 1000 metres’ and 200 metres’ visibilities into the definition has added 330 dust storms to the Dust Event Database (DEDB).

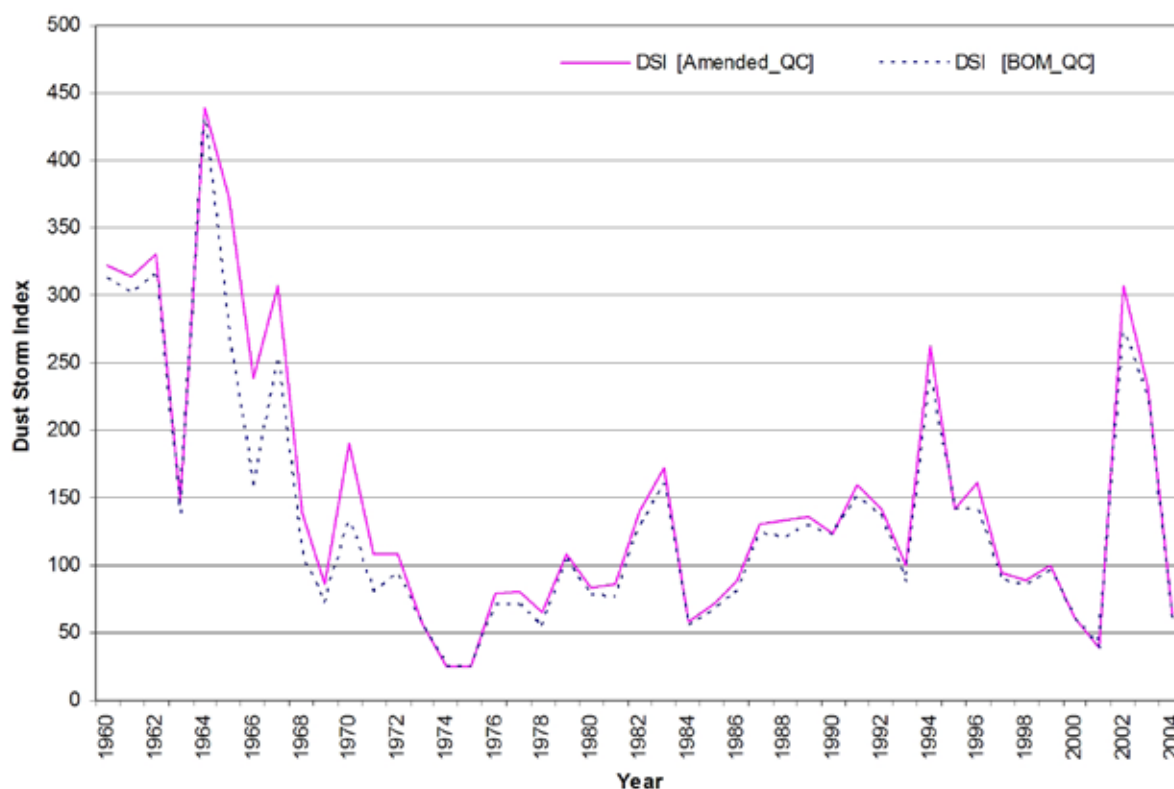


Figure 5: Improved DSI compared with BoM DSI 1960–2004

Note: The improved DSI (solid line) has increased the measured wind erosion activity (1960–2004) and this change is greatest in the 1960s period of high wind erosion activity

3.1.2 Quantitative testing of different measures of wind erosion rates

While mapping of wind erosion has steadily improved by using meteorological records, until recently was no independent quantitative measure of how much an improvement the new methods brought. McTainsh et al. (2004a) completed a series of analyses in the Lower Murray Darling Catchment Management Authority Area, correlating field-based dust concentration measurements with various measures of wind erosion rate using meteorological data. This study (McTainsh et al. 2004) found that the DSI has the highest correlation with field-measured dust concentrations (r^2 0.98). In addition, although calculated dust concentrations from meteorological observations of visibility had slightly lower correlations with field-based dust concentration measurements (r^2 0.90), this approach has significant potential for development as a wind erosion mapping tool (and has since been used by McTainsh et al. 2005) which is discussed in 3.1.4 below.

3.1.3 Data confidence maps to reflect observation frequencies

More than 70% of meteorological stations make observations at 0900 and 1500 hours (local time) and between 35% and 50% of stations record between 0900 and 2100, while <15% record between 0000 and 0600 (Figure 6).

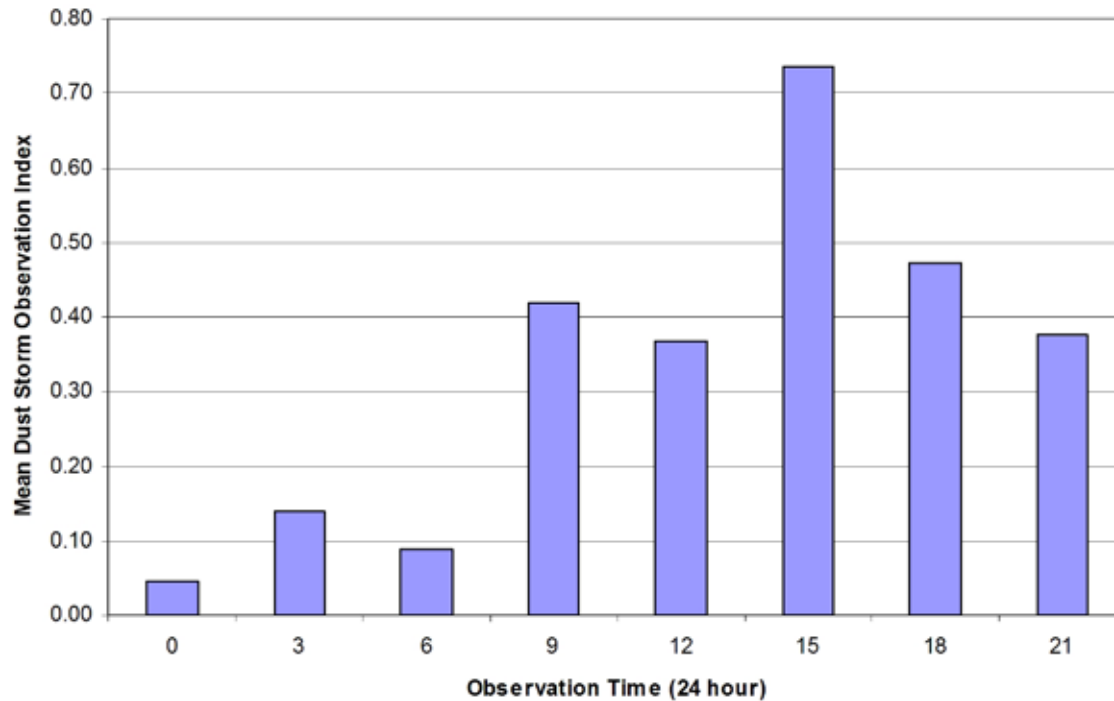


Figure 6: Observation frequencies at different times

This means that stations with high observation frequencies (e.g. with observations at three-hourly intervals) will have a much greater influence on spatial patterns of wind erosion than stations with low observation frequencies (e.g. only making observations at 0900 and 1500). At locations where observations are undertaken at night (mainly airports), observers use lights or objects that can be seen at night to record visibility.

Data confidence maps based on the observation frequency of stations (expressed as a %) across the continent provide a guide to the areas where low observation frequencies may limit the accuracy of wind erosion mapping. For example, in Figure 7 there are a number of areas with red-orange-brown colouring that have low observation frequencies for 2004. This is useful information when interpreting the DSI wind erosion map for 2004 (Figure 8). It indicates that the low erosion rates in, for example, central Queensland, north-west Victoria, and south-west Western Australia may be an artefact of the low observation frequency of stations in that region.

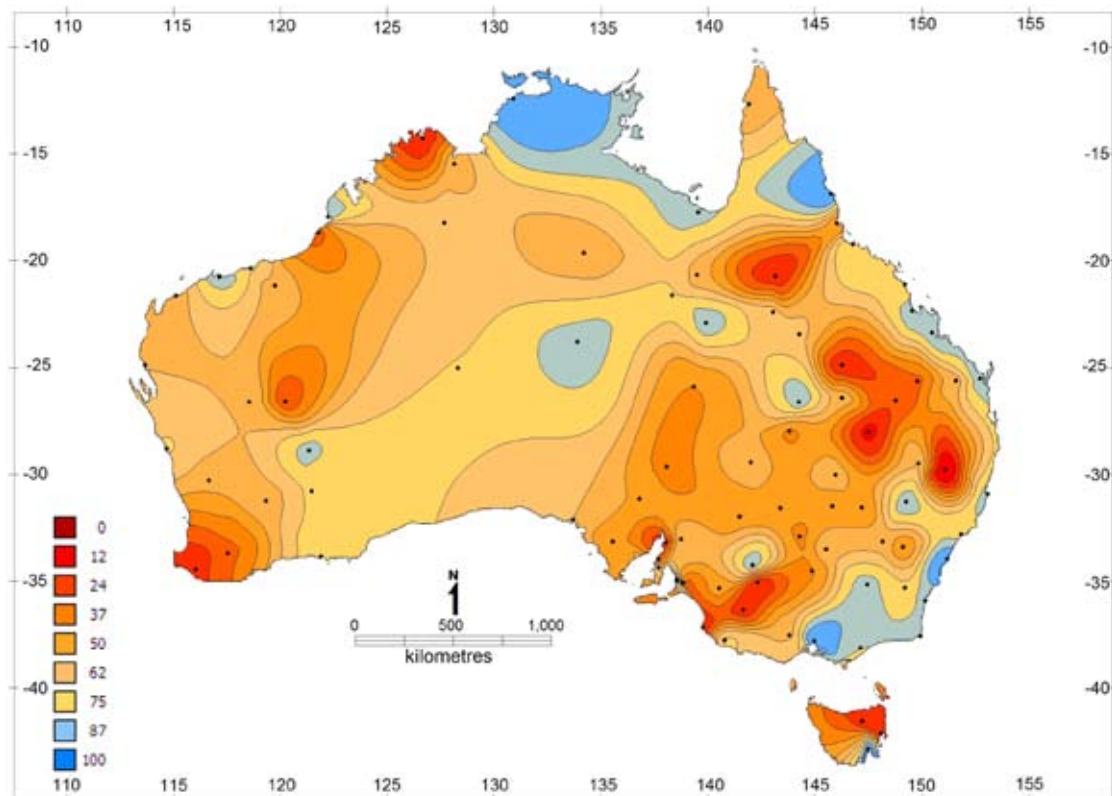


Figure 7: Map showing the % observation frequency at 100 long-term stations in 2004

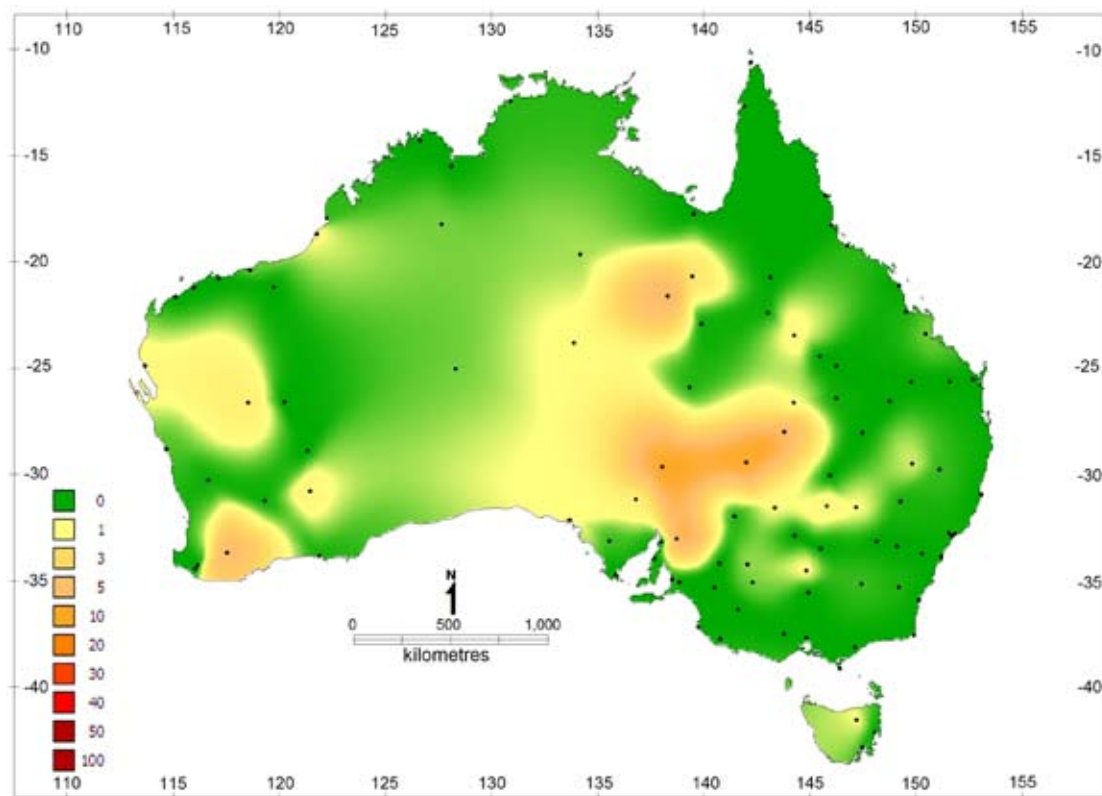


Figure 8: Map of wind erosion activity expressed as the total DSI at each of 100 long-term stations in 2004

3.1.4 High resolution wind erosion mapping on an event basis

Until recently, most of the wind erosion mapping using meteorological records has been for long-term environmental audit purposes (e.g. National and State *State of the Environment* Reports). Because very large amounts of soil are lost in a small number of severe dust storms, there has been a recent move towards measurement and modelling of the dust loads in individual large dust storms (McTainsh et al. 2005, Shao et al. 2006). This has presented new challenges for mapping wind erosion from meteorological records, such as the need to map dust concentrations, rather than DSI (because these data are needed to calculate dust loads in individual dust storms), and to access the maximum number of stations recording on a three-hourly basis.

Figure 9 maps the measured dust concentrations during a dust storm at 0600 on 23 October 2002 using conventional data access methods (i.e. the methods used for annual wind erosion mapping, using long-term stations). The shading on Figure 9 provides a relative measure of dust concentration.

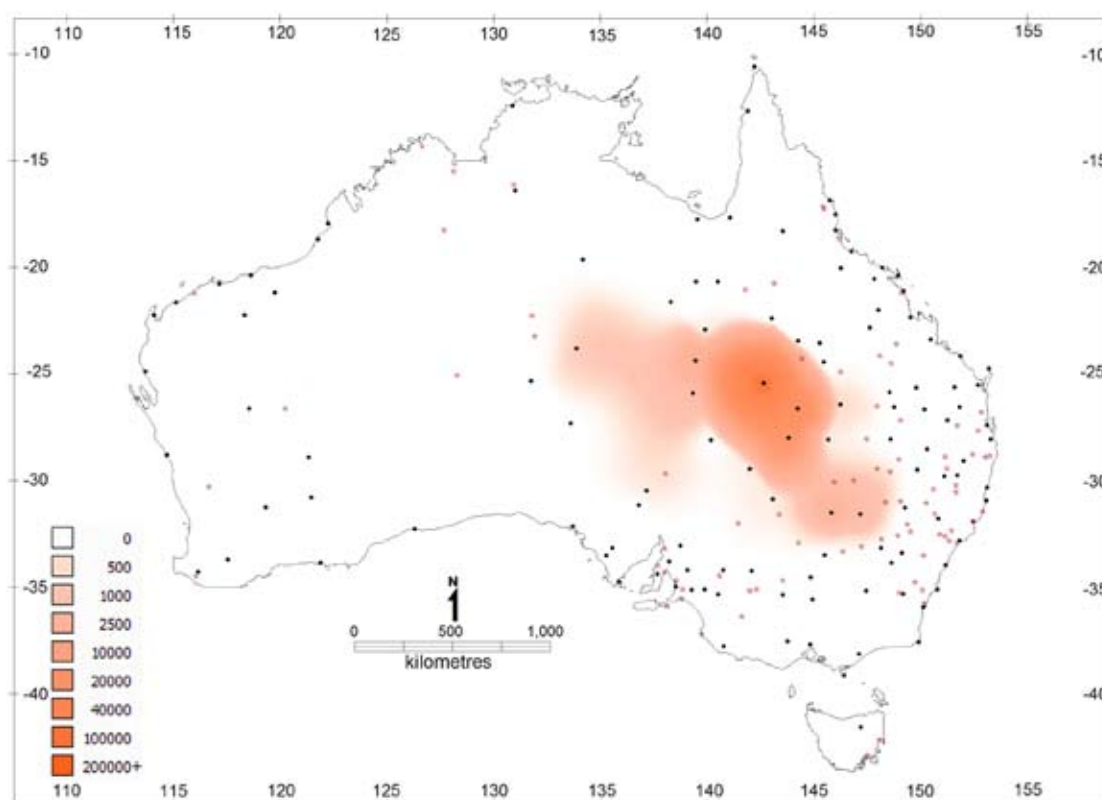


Figure 9: Dust event map at 0600 hours 23 October 2002 represented by dust concentrations ($\mu\text{g.m}^{-3}$) at long-term station locations

Figure 10 maps relative dust concentrations for the same event and at the same time and date, but using new data access methods. These new methods involve data aggregation over a three-hour period, using data from the past weather field (as well as the present weather field) at 0600 23 October 2002. Also, locations not recording at the time (shown as red dots) are not included in the spatial interpolation. These new methods are clearly identifying new areas of recorded dust concentration, thus providing more complete and higher resolution maps of wind erosion.

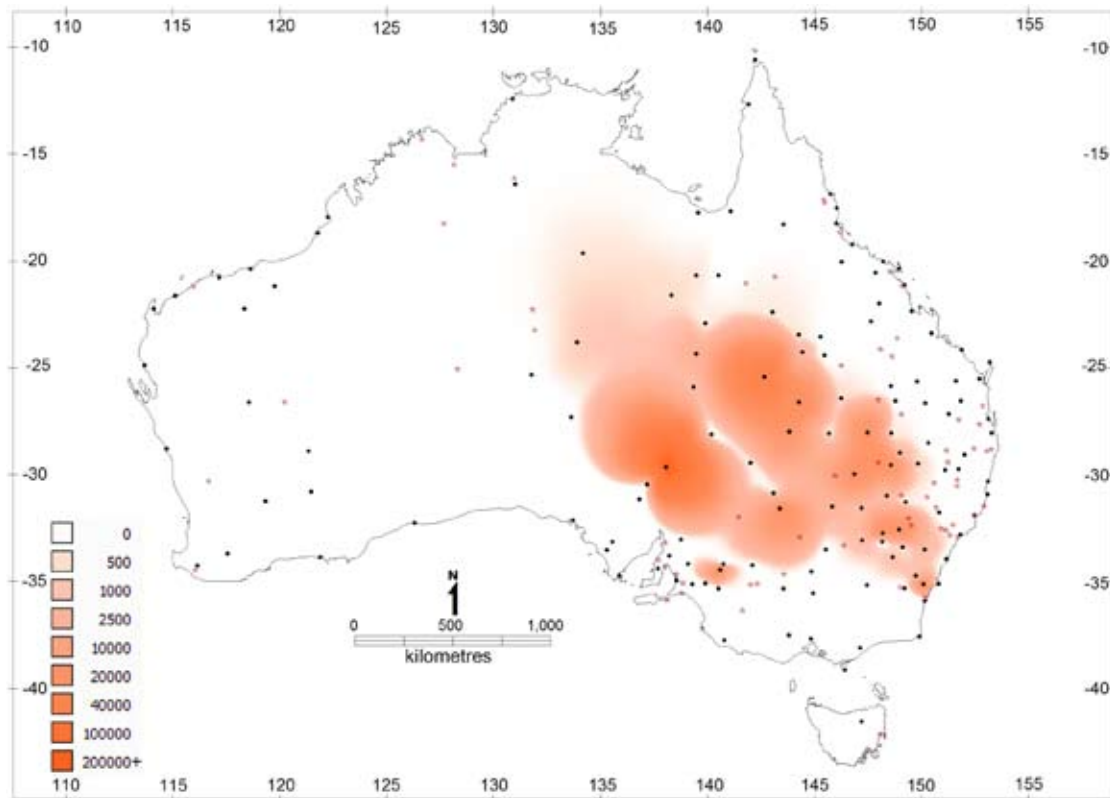


Figure 10: Dust event map at 0600 23 October 2002 represented by dust concentrations ($\mu\text{g.m}^{-3}$) using improved data access methods

Note: Red dots refer to stations not recording at this time

3.2 A numerical wind erosion assessment model (IWEMS)

Significant advances have been made in wind erosion modelling using the Integrated Wind Erosion Management System (IWEMS) model of Lu and Shao (2001). These include:

1. testing of the model for broadscale mapping in the Lower Murray–Darling Catchment Management Area (LMDCMA)
2. setting up of a research infrastructure in collaboration with Professor Shao to run the model in Australia on a routine basis.

3.2.1 Testing of the model for broadscale mapping in the Lower Murray–Darling Catchment Management Area (LMDCMA)

It was initially planned to use the Wind Erosion Assessment Model (WEAM) (Shao et al. 1996) for mapping wind erosion in the LMDCMA, but due to model developments by Professor Shao, the more comprehensive Integrated Wind Erosion Assessment Modelling System (IWEMS) (Lu and Shao 2001) has been used.

The modelling was undertaken by Professor Shao at the City University of Hong Kong. IWEMS takes into consideration the atmospheric and land-surface conditions (e.g. wind speed, rainfall, etc. and soil type, vegetation cover, etc.) and estimates wind erosion quantities such as sand flux (Q) and dust flux (F). Other wind-erosion related quantities, such as threshold friction velocity (u^*_t) and friction velocity (u^*) are also calculated.

During this study, IWEMS was successfully tested against an independent data set based on visibility data for 22–24 October 2002 dust storm. These results have been accepted for publication (Shao et al. 2006). The IWEMS model was then run with a two-hourly time step to calculate the monthly erosion rates of south eastern Australia.

The study area is south-west, NSW bounded by 139°E to 146°E and 31°S to 37°S. The area is divided into a number of cells of 10 kilometres in size. The wind erosion quantities, among many others, are calculated every two minutes. From the model outputs, the monthly averages of sand flux, dust flux etc. were calculated and mapped for the study area.

Figure 11 shows the average predicted monthly erosion rates (expressed as the horizontal soil flux Q $\text{mg m}^{-1} \text{s}^{-1}$) from July 2003 to June 2004.

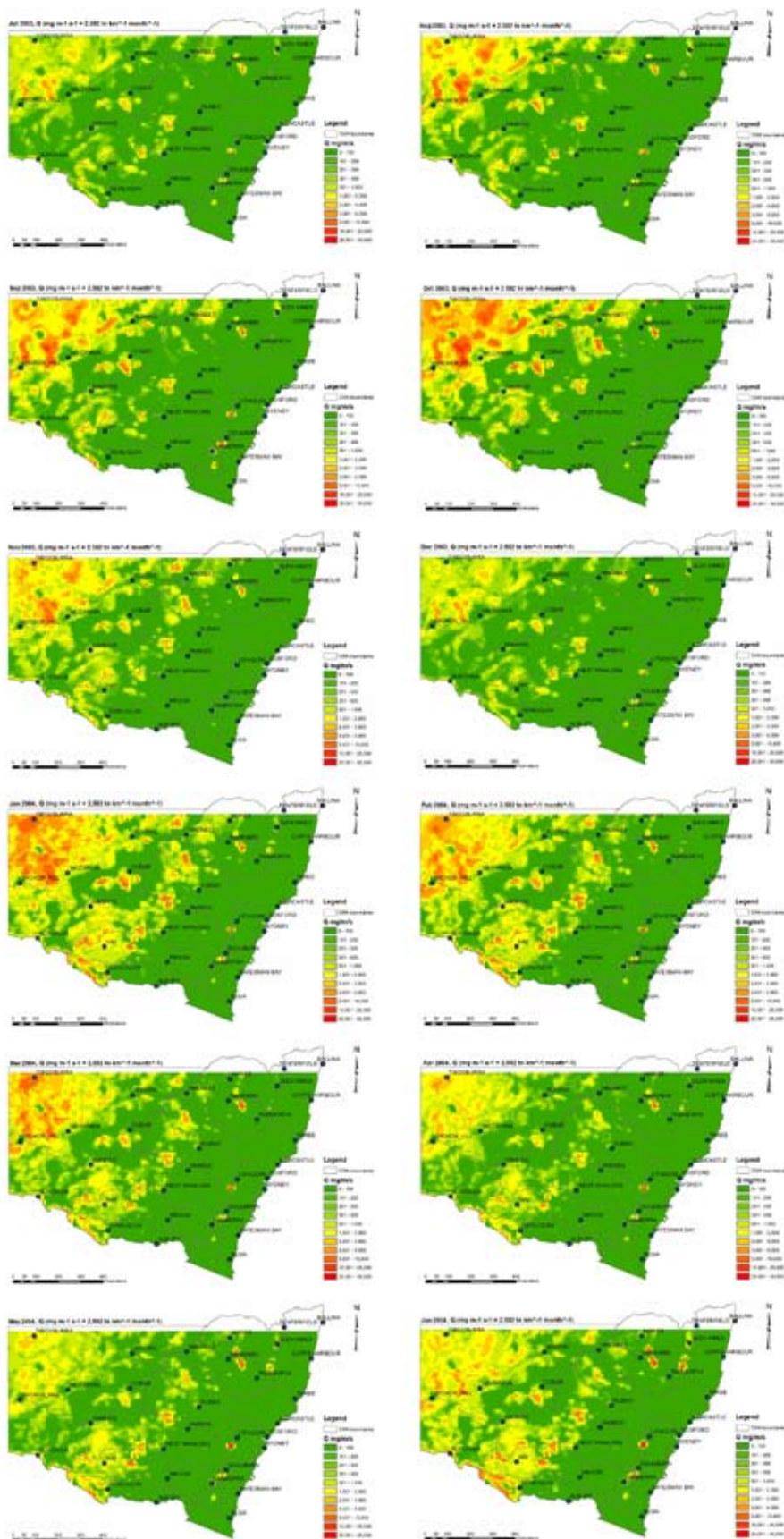


Figure 11: Average predicted monthly erosion rates (expressed as the horizontal soil flux Q in $\text{mg m}^{-1} \text{s}^{-1}$) July 2003–June 2004

Monthly wind erosion maps

Within the study period of 12 months, there is monthly variation of both the amount and the intensity of erosion predicted by the modelling. The area in the north-west of NSW shows some signs of erosion in all months with less erosion being predicted in the wetter parts of the study area. February and March were the months with the highest predicted erosion levels. Within the study area, northwest NSW and lower Strzelecki Desert were the areas with the highest predicted erosion levels.

The predicted erosion intensity increases from July 2003 to March 2004, then decreases. The extent of the area affected generally increases during the study period, with much of the wheat belt (with annual average rainfall less than 500 mm) indicating some level of erosion, even in June 2004. The riverine plain around Hay shows signs of increased erosion in 2004. This area is dominated by grasslands which are more responsive to rainfall than woody landscapes like the mallee to the west of Hay. As cover levels dropped on the grasslands, erosion increased.

As seen from Figure 12, the study area had average to below average rainfall for the period of the modelling simulation. Figure 11 also indicates that those areas above about 500 mm annual rainfall have little predicted erosion.

Monthly rainfall maps

The monthly variations in predicted wind erosion are partly explained by rainfall.

Figure 13 shows the monthly variation in rainfall expressed as deciles. As can be seen, there was an extended dry period over the previous 12 months with only August 2003 and December 2004 having above average rainfall in the study area. This exacerbated the erosion within the study area.

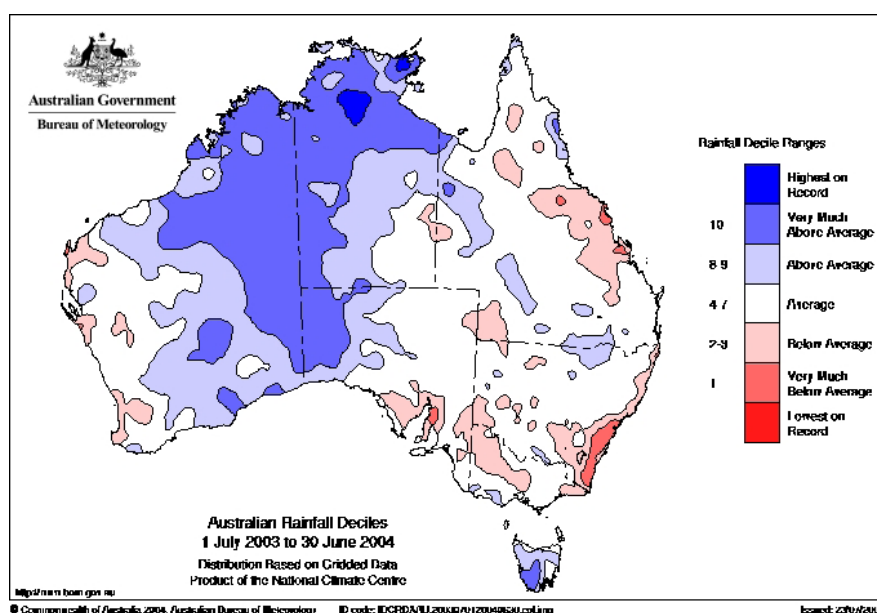


Figure 12: Decile rainfall map July 2003–June 2004

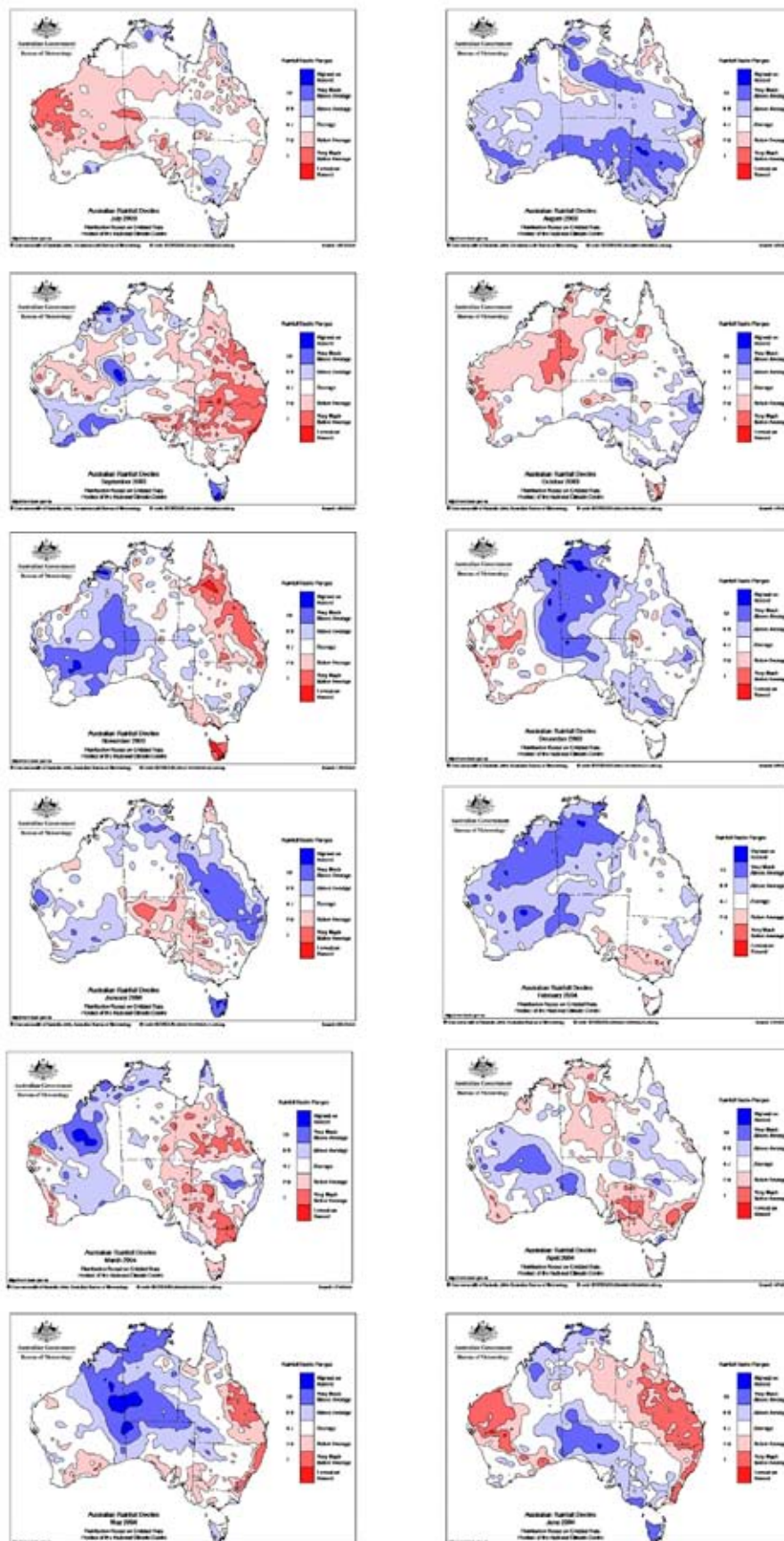


Figure 13: Decile rainfall maps July 2003–June 2004

Monthly wind speed maps

Wind speed is a key determinant of wind erosion when soils are dry, have low ground cover and are loose. While wind speed varies from month to month, it does not necessarily follow that windy areas had erosion. For example, the eastern parts of the study area did receive high winds, yet they did not show any predicted levels of erosion because ground cover levels did not fall below threshold levels. It is therefore more useful to examine wind speed distribution in wind erosion areas only. Figure 14 shows the magnitude of wind speed for areas with $Q > 0$. In general north-west NSW and the Mallee country are relatively windy. The north-west has higher winds due to the acceleration of the wind by the Barrier, Grey and Flinders ranges. As the predominant direction of eroding winds is from the south-west, and as wind speed decreases inland, lower wind speeds were experienced in the north-east of the state, around Moree.

The monthly variation in wind speed is shown for selected months in Figure 14. The high winds of February corresponded with dry conditions and resulted in high wind erosion levels. Normally, wind speeds decrease from March to August; however, there were unseasonably high winds in June 2004 and this resulted in wind erosion levels not normally seen in this area.

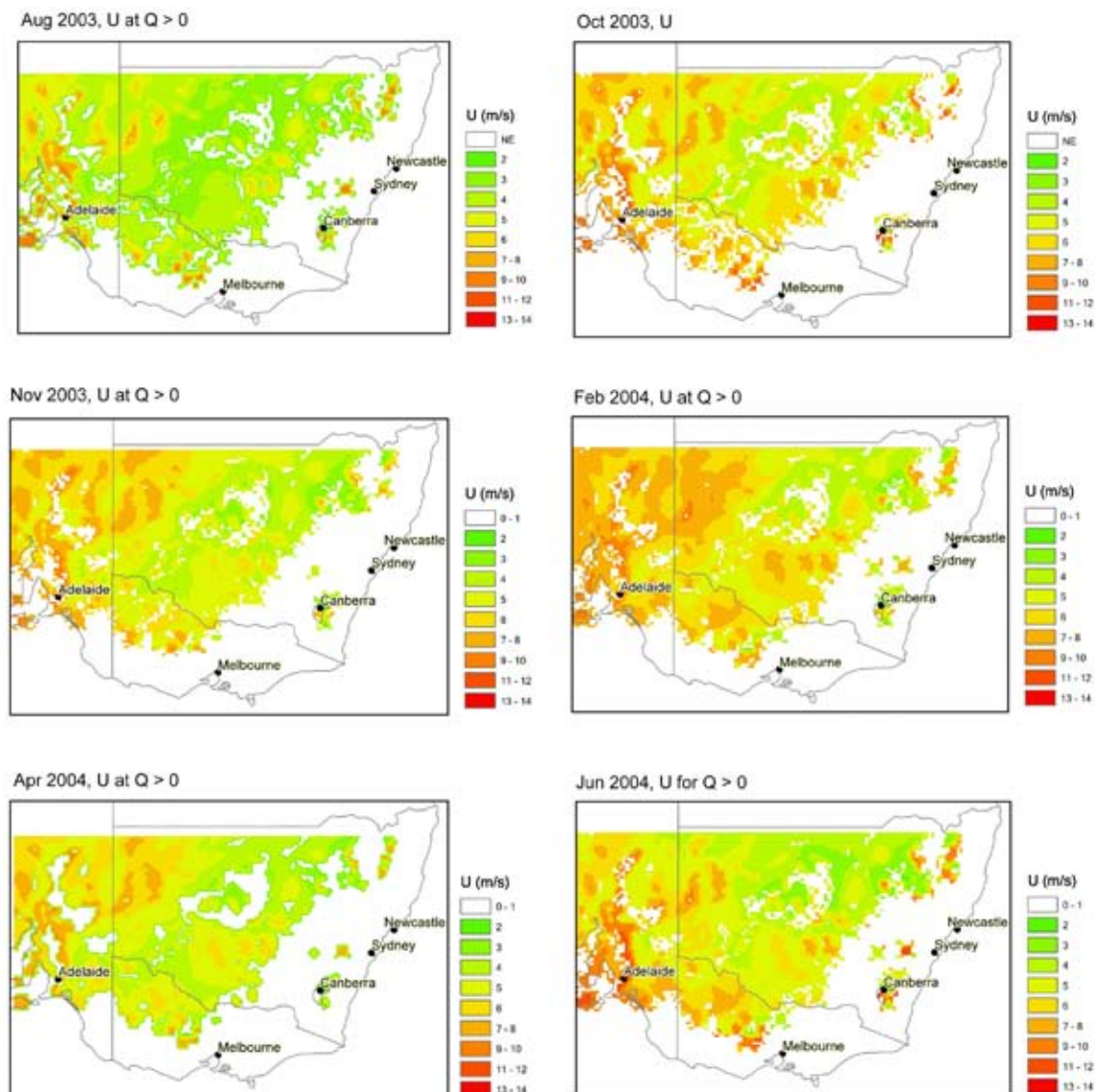


Figure 14: Selected monthly wind speed maps for those areas that had erosion (i.e. $Q > 0$)

Modelling conclusions

The north-west part of the study areas has the highest predicted erosion levels reflecting the low rainfall, ground cover and moderate winds. During the 2003–04 period, predicted erosion generally increased each month, expanding both spatially and in intensity. By March 2004, erosion levels in the southern part of the study area were quite high. This was largely due to the failure of the autumn break. Lack of grass cover as estimated from the normalised difference vegetation index (NDVI) satellite data saw the Mallee and riverine plain around Hay becoming major source areas.

This study has shown that wind erosion patterns are a result of multiple factors and that these can be successfully assessed within the IWEMS modelling framework. The accuracy of the model was tested for a severe dust storm for the period 22–24 October 2002 and was found to provide reliable estimates. The 2002 dates were chosen because there was a significant amount of data available for this period.

3.2.2 A new research infrastructure for using IWEMS in Australia on a routine basis

The utility of the IWEMS model (now renamed the Computational Environmental Management System (CEMSYS) for wind erosion assessment and mapping in Australia has been demonstrated in Shao et al. 2006. With this capacity, the logical next step is to develop the capacity to regularly run the model in Australia. This has been achieved through the cooperation of the model developer, Dr Shao (City University of Hong Kong) and Dr Harry Butler (University of Southern Queensland) who will take over the running of the model using the Griffith University computer infrastructure.

3.3 An Intelligent Knowledge-Based System (IKBS) model for mapping of land type erodibility

The Australian Land Erodibility Model (AUSLEM) is being developed in the project by Nicholas Webb (PhD student at University of Queensland – supervised by McGowan, McTainsh and Leys). The basic structure of the model has been developed, input data sets established and initial maps produced. This work has recently been published (Webb et al. 2006a).

4. Prototype methodologies for quantitatively discriminating accelerated wind erosion rates, and soil condition indicators for use on property-based Environment Management Systems (EMS)

A significant research focus has been on developing conceptual models and prototype methods for:

1. Assessing accelerated wind erosion (i.e. erosion linked to land management as opposed to climate)
2. Development of a remote sensing–based Vegetation Land Condition Indicator
3. Producing quantitative indicators of soil degradation by wind, for use at property scale.

4.1 Assessing accelerated wind erosion

Perhaps the largest wind erosion research challenge is to quantitatively discriminate the component of wind erosion rates that has been accelerated by land use and land management. Three quite different approaches were investigated here using:

1. Meteorological records of wind erosion Australia-wide
2. The IWEMS wind erosion model
3. Remote sensing of vegetation.

The outcome of this development work is that all three approaches have merit and are worth pursuing further (and are discussed in more detail below). This methodological development work has also recently been summarised in the outcomes of a meeting of the national Wind Erosion Expert Panel (of which McTainsh and Leys are members), which recently reported to the National Committee on Soil and Terrain of the National Land and Water Audit (NLWRA).

4.1.1 Meteorological records of wind erosion Australia-wide

The approach to discriminating land use impacts upon wind erosion which has been adopted here is to standardise wind erosion rates for climate (i.e. to produce climate-adjusted wind erosion rates). Therefore, if the climate-adjusted erosion rate at a location has changed through time it is most likely due to changing land use. The wind erosion record (1960–2004) in central Australia (in particular the Alice Springs region) was analysed using rainfall-adjusted erosion rates (i.e. erosion rate, measured by the DSI, per 10 mm of rainfall) and compared with those for eastern Australia (Table 1).

During the 1960–1965 period, the rainfall-adjusted wind erosion rate in central Australia was 5.6 times that of eastern Australia, whereas from 1966 onwards the rates were very similar in eastern and central Australia. This long-term trend reflects the well-documented period of accelerated wind erosion in the area around the Alice Springs airport in the early 1960s, which was largely brought under control by the introduction of buffel grass in the mid 1960s (McTainsh et al. 2006a).

Table 1: Rainfall adjusted erosion (DSI per 10mm of rainfall) in eastern and central Australia (1960–2004)

Sector	1960–1965	1966–1970	1971–1980	1981–2004
Eastern Australia	0.37	0.27	0.06	0.11
Central Australia	2.06	0.28	0.11	0.12

4.1.2 The IWEMS wind erosion model

Wind erosion as predicted by IWEMS is the sum of the natural level of wind erosion caused by the weather and the additional levels of erosion caused by land management. For example, a National Park within a wind erosion prone area with the appropriate grazing pressure will have a lower level of erosion than the same area farmed and managed with inappropriate farming levels.

As confidence in the IWEMS modelling framework grows, the management effects on wind erosion in a given region can be quantified by firstly modelling the erosion rates for optimal vegetation cover (e.g. as for the National Park example above), then re-running the model with actual wind erosion rate. The differences between the two erosion rates would then be the accelerated wind erosion rate.

4.1.3 A remote sensing–based Vegetation Land Condition Indicator

Ground cover (both vegetative [live and dead plants] and non-vegetative [gibber/stone and soil crusts]) offer good protection for the soil. Vegetation cover mapping of the Alice Springs Pastoral District (1972–2002) has been completed using Landsat data to provide land management input data for regional environment management systems (EMS) (see Appendix 2). Maps of wind erosion of the same region have also been produced from the Dust Event Database (see Appendix 3) and this work is being developed further for publication.

Field surveys of ground cover play an important role for ground-truthing remote sensing and these have been tested in the Murray–Darling Catchment Management Area. In-paddock methods that assess ground cover and soil aggregation were successfully trialled during the project. An example of one community group’s response is given here:

The method, I think, is a fairly quick and easy measure to compare paddocks and soils. It is hard for me to say if the ratings are correct or not (possibly some of the paddocks that I would have thought would blow were still in the low category because of the small broken up stubble (by sheep) on the surface), but it is good to have a rating. The stubble cover per cent seems to be higher than what we would visually give it but that probably doesn't matter. As with most methods it is good to have the same operator doing the soil extraction and sieving, as depending on the operator's interpretation of the instructions this can make a difference. But overall a good, quick and easy method.

(Anne Jackman, Birchip Cropping Group)

The comment that the measured stubble cover was higher than the group observed it to be is more an indication of people's perceptions than a criticism of the method. In fact, very few observers ever 'calibrate' themselves by using two measurements. In this regard, we believe there are educational advantages of mixing observations with measurements because this encourages the user to think about the indicator being measured.

Conclusions

This research project has achieved its objectives, and research productivity has exceeded expectations in several areas. This places the research team in an excellent position to proceed to the next stage of developing and fully testing a suite of land condition indicators which can be used to quantify sustainable land management in desert Australia.

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Appendix 1: Report on the development of a remote sensing based Vegetation Land Condition Indicator

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Summary

The work reported here explores the possibility of incorporating regional analyses of remotely sensed cover levels through time into an environmental management system (EMS) for the pastoral industry. It is envisaged that such an EMS would support the credentials of claimed environmentally benign ('green') production of meat and/or fibre from specified rangeland regions. As a possible demonstration, a more specific component of such an EMS is explored here: whether past grazing practices in parts of central Australia could have contributed to risk of enhanced dust generation and – by corollary for an EMS – which areas appear to have low risk of dust generation.

As a way of summarising results, and as a possible vehicle for reporting the outcomes of property grazing management in an EMS, I propose a land condition indicator (LCI) that reports paddock cover levels compared with the regional average (at each point in time). Because there is inherent variation in cover according to land type, indicator values are reported by mapped land system. Land systems within paddocks that have average cover below the regional average for that land system (by $> \frac{1}{2}$ SD) are assigned a poor rating. Conversely, land systems with average cover above the regional average for that land system (by $> \frac{1}{2}$ SD) have a good rating. However, cover doesn't necessarily decline with poor grazing management across all land systems. Rather, I have grouped land systems into three categories:

1. Those where cover does tend to decline with inappropriate grazing. Below average cover here is seemingly undesirable for sustained environmentally sound pastoral production and may contribute to enhanced dust generation.
2. Cover increases with fire suppression and/or poor grazing management due to woody thickening. Below-average cover may be inconsequential for dust generation (because of residual tree and shrub cover) and perhaps favourable for sustained pastoral production – provided reduced cover is due to a lower woody density and not to excessive grazing of the ground layer (herbage). Above-average cover probably assists dust suppression but is probably detrimental for sustained production where woody thickening contributes to reduced long-term forage availability.
3. Cover levels are largely affected by wildfire (in addition to rainfall variation) – these are true 'desert' land systems. Below average cover may matter as a potential source of dust, particularly where dry years follow extensive wildfire and the natural recovery process is retarded. However, below- and above-average cover are considered to be of minimal importance for sustained pastoral productivity as these 'desert' areas grow little palatable forage and are of minor importance for sustained production.

Cover results are reported from $>150,000$ km² in the southern half of the NT (pastoral leases covered by map sheet SF53 and the northern half of SG53). The basis for analysis was:

- 11 image dates of radiometrically calibrated Landsat TM and MSS imagery between 1972 and 2002. The PD54 index was used to estimate vegetation cover. Index values were then converted to approximate percent cover.
- Mapped land systems (Perry et al. 1962) as the basis for stratifying land types – grouped as described above.
- Two distance-from-water classes (≤ 3 km from water and > 3 km from water) – with distance from water used as a surrogate of grazing pressure to test for obvious grazing effects.
- Calculate average cover for each land system for each image date. Then determine which land systems in which paddocks had cover above, within or below the thresholds specified above (i.e. cover $> \frac{1}{2}$ SD above or below the 'global' mean for that land system). (Analyses restricted to land systems with > 20 km² area in paddocks > 50 km².)

- Report statistics and map LCI scores using the above stratification (i.e. cover likely to decrease with inappropriate grazing, increase with fire suppression and/or poor grazing, or cover largely affected by wildfire).

For those land systems considered to show cover decline with inappropriate grazing management:

- There were differences in mean cover among land systems at each image date (epoch) with these differences broadly related to land types – i.e. treed and shrubby land systems had greater cover than more open (less timbered) land systems. Mean cover on individual land systems also varied through time and I show how these changes were broadly related to antecedent rainfall for a small demonstration area.
- Grazing effects were more apparent on some land systems, in that mean cover in the 0–3 km distance increment was less than that present beyond 3 km. Similarly, the 0–3 km distance class had a smaller number of land system–paddock combinations with average cover consistently below the land systems average compared with beyond 3 km. Conversely, slightly more land system–paddock combinations consistently scored in the ‘above’ cover category further from water compared to closer to water.
- Predominant LCI values were mapped (where land systems occupied >20 km² area in paddocks >50 km²). (‘Predominant’ is defined as the dominant LCI score from more than half of the available 11 image dates.) Mapped areas of predominantly below-average cover were generally small and dispersed and appeared to have little significance as possible sources of enhanced dust generation. The locations of these below-average cover areas may have some value within a regional EMS for indicating where pastoral practices are perhaps unsustainable and need review.

For those land systems where cover tends to increase due to woody thickening resulting from fire suppression and perhaps inappropriate grazing management:

- There was no pattern of consistent cover increase through time. Cover is likely to increase in some areas between consecutive image dates through woody thickening with cover increase offset at other times by grazing (i.e. removal of herbage cover), particularly in dry years.
- Cover levels were generally lower closer to water (0–3 km) compared with further from water (>3 km). Across all stations, three times as many paddock–land system combinations showed predominantly lower levels of mean cover between 1972 and 2002 closer to water compared with predominantly higher cover. This suggests that grazing effects in paddocks showing the most marked deviations from overall mean cover of each land system were quite strong and were acting to reduce cover more so than any cover increase caused by localised woody thickening. Further from water (>3 km), there was an approximately equal number of paddock–land system combinations (summed across all stations) with cover either predominantly above or below the global mean of each land system in this ‘woody increase’ group.
- Mapped areas with predominantly below – or above – average cover were relatively small and widely separated – a similar result to that presented for those land systems where cover tends to decrease with inappropriate grazing.

Compared with the above two groupings, land systems where cover was mainly affected by wildfire (and rainfall) had:

- A smaller difference between the percentage of land system–paddock combinations in the higher (‘above’) and lower (‘below’) cover categories. Periodic (or in some cases, episodic) fire and the spatially distributed variable stages of post-fire regeneration probably had a moderating effect on the range of cover levels determined.

- A smaller difference in the percentage of land system–paddock combinations across the two distance-from-water classes. This probably results from the combined effects of recent fire on reducing cover wherever it had occurred and minimal grazing impact on lowering average cover levels closer to water (compared with further from water).
- Mapped areas of land systems where cover was affected by wildfire with predominant cover above or below the regional land system average were more extensive and clumped than for the two previous land-system groupings. This is considered to be due to the greater regional extent of these ‘desert’ land systems and the large size of paddocks in these desert areas. It may be that the regional occurrence of extensive areas of below-average cover following fire, particularly in dry years, contributes to atmospheric dust levels recorded at Alice Springs (and perhaps at other meteorological stations).

The land condition indicator is entirely exploratory at this stage, and mapped scores have not been validated in any way. If there is merit in the analysis approach used, then it may be more valuable to focus on areas with below-average cover in the very dry years (subject to greater availability of suitable archival imagery) rather than mapping the predominant LCI score across an extended image sequence. It is probably also useful to explore the effect of adjusting the LCI thresholds (i.e. separate from the $\pm 1/2$ SD of each land system mean). It is probably also desirable to include additional imagery of stations fringing the Simpson Desert, and the desert itself, as this area may be a significant source of dust observed at the Alice Springs and Jervois meteorological stations.

Factors limiting the conclusiveness of results presented in this regional analysis include:

- The exploratory (and perhaps flawed) nature of the proposed land condition index. The index needs much further intellectual development, discussion and testing before it can be a plausible component of an EMS suitable for the pastoral industry.
- Inherent variation within mapped land systems and the stratification used to group land systems. Most apparent here is that for those land systems where cover is considered to decrease with inappropriate grazing, cover may actually increase on some land units and decrease on others. Available mapping does not allow additional separation to analyse these contrasting units separately.
- The variable extent of different land systems. Some are quite ‘local’ (e.g. mapping alluvial features or soil and vegetation types) while others are regional in extent – particularly the desert and mulga shrubland land systems. Regional rainfall differences on cover within a Landsat image date are probably better damped within the former compared to the latter. For example, localised rainfall effects may mean that a land system–paddock combination has considerably different cover to the land system mean where a land system is regional in extent compared to local.
- The variable size of paddocks across the analysis region. There were many smaller paddocks and a considerable number of very large ‘paddocks’ (almost the entire area of some minimally developed stations). This size variation, combined with the variable area and extent of land systems (see above) provides an unequal-area basis for analysis and may distort the comparison/interpretation and mapped display of results presented.

1. Introduction

Wind erosion is widespread in parts of arid Australia, but significant knowledge gaps persist in relation to the history and spatial extent of the problem, the extent to which pastoral activities accelerate wind erosion rates, and the potential for improving long-term sustainability of pastoral production by reducing accelerated wind erosion. Wind erosion is a natural geomorphic process within deserts, with some land and soil types more predisposed to this natural phenomenon. Nevertheless, grazing is implicated as a cause of accelerated rates of wind erosion in some pastoral areas because of reduced vegetation cover and trampling of the soil crust. However, there are few reliable quantitative data available which apportion the component of overall wind erosion contributed by inappropriate grazing practices.

Persistent vegetation cover has an ameliorating effect on both wind and water erosion (Leys 1991, Leys et al. 1999, McTainsh et al. 1989, McTainsh and Leys 1993, Hesse and McTainsh 2003, Johns 1983, Lang and McCaffrey 1984, McIvor et al. 1995, Galle et al. 1999). The management action targets of most regional natural resource management groups in the rangelands now advocate maintenance of minimum levels of cover (e.g. NT Integrated Natural Resource Management Plan available at <http://www.nt.gov.au/nreta/naturalresources/plans/inrm/inrmplan/index.html>). This builds on the earlier requirement of western NSW pastoral leases to maintain at least 40% cover where cover is broadly defined as intact vegetation – litter, logs and other organic debris – and stone mantling. Rather than enforce this requirement, Hacker (2004) argues that acceptable cover levels might be better maintained through the payment of incentives or rewards to pastoral lessees to achieve desired outcomes.

An alternative approach to legislation or administration for achieving and recognising ecologically sustainable management is the process embodied in environmental management systems (EMS). Here pastoralists, either singly (e.g. a pastoral company) or in groups, document and publicise the environmental components of their management system that meet expected (or anticipated) standards. The driver for this process is either (1) improved commodity prices by meeting specified compliance requirements for a niche market or, (2) demonstrating good stewardship of land and other natural resources to the public and/or government. Presumably, a desired or anticipated outcome here is reduced encumbrances, for example by way of legislative constraints, on continued use of the land and allied natural resources for operating the pastoral business into the future. Producers can proceed to formal accreditation if they wish, for example as specified in international standards such as ISO 14001. Recent experience among EMS groups operating in the rangelands, however, suggests that the extensive bureaucracy associated with meeting formal requirements do not compensate for the minimal additional benefits achieved, and an alternative, less formal approach is preferable (Banney 2001, Carruthers 2001). The requirements for informal endorsement or acceptance of an EMS are generally not specified but appear to be related to what is considered ‘best practice’ management of the environment – either in total, or for particular outcomes (e.g. enhancement of a particular species or ecosystem).

1.1 Land Condition Indicator

The content and operation of EMSs is still evolving in rural Australia. However, it would be reasonable to expect that an operational system for pastoral land use in the rangelands would include a component that reports suitable (sustainable) management of the soil and vegetation resources. Within this, sub-components could report on wind and water erosion – either by amount (magnitude, timing, duration, etc) or probably more realistically by risk of likely erosion. A critical element in determining risk across the extensive areas managed by most pastoralists would be maintenance of acceptable/agreed levels of vegetation cover.

There are established methods for monitoring vegetation cover using remote sensing (e.g. Pickup et al. 1993, Karfs 2002). The global coverage provided by satellite data and the existence of archival imagery, particularly for Landsat since 1972, means that remote sensing should be able to contribute information on change in cover through time as part of an operational EMS. Because cover is dynamic and particularly influenced by recent rainfall, the 30-year+ archive of Landsat imagery provides important context against which to judge current levels. The attractiveness of this data source is increased now that the Australian Greenhouse Office (AGO) has released their calibrated continental coverage spanning 11 image dates (epochs) – see http://www.ga.gov.au/acres/prod_ser/agosuite.jsp for details and Furby (2002) for image processing detail sitting behind this image suite.

The vegetation cover present on each land type varies with season (rainfall) as well as with grazing (utilisation), with fire also having a profound effect in some landscapes (e.g. spinifex sandplain). Thus, there is a need to separate grazing effects on the vegetation from those due to rainfall to determine land condition. In central Australia, grazing gradient methods (Pickup et al. 1993; Bastin et al. 1993a, 1998) are one way of determining grazing impacts (i.e. land degradation). Land has declined in condition where vegetation cover fails to respond in the vicinity of watering points following rainfall that promotes maximum vegetation response elsewhere.

Appropriate application of grazing gradient methods requires considerable technical expertise and is considered inappropriate for rapid regional appraisal as part of an EMS. Rather, I propose a simpler method that indicates condition in a relative sense (cover above, below or within a threshold of the land type mean) for different cover responses related to grazing and fire (details provided in the Methods section).

1.2 This report

This report describes how cover varied by landscape type (mapped land systems) within management units (larger paddocks on pastoral leases) in central Australia between 1972 and 2002. I demonstrate how paddocks with similar land types can be compared on the basis of deviation in cover levels through time – as categories of ‘above’, ‘below’ or ‘close to’ mean land-system cover levels. With further testing, this type of cover-based ranking may provide an indication of wind erosion risk that could be included in a regionally based EMS.

2. Methods

2.1 Analysis area

The analysis area is the western and north-western portions of the SF53 and SG53 map sheets in central Australia (Figure A1.1). This area (208,300 km²) was selected because it has consistent coverage of Landsat data from the AGO image archive between 1972 and 2002. Overlaid pastoral lease boundaries show that available imagery covers much of the area used for grazing in the southern NT.

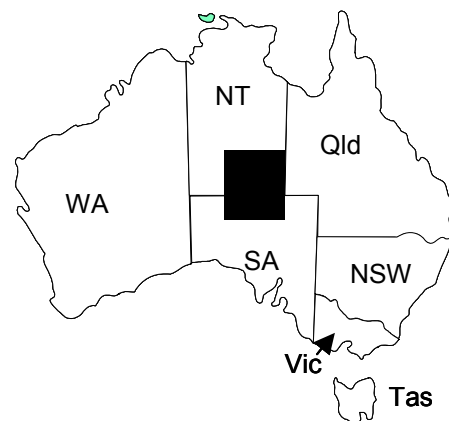
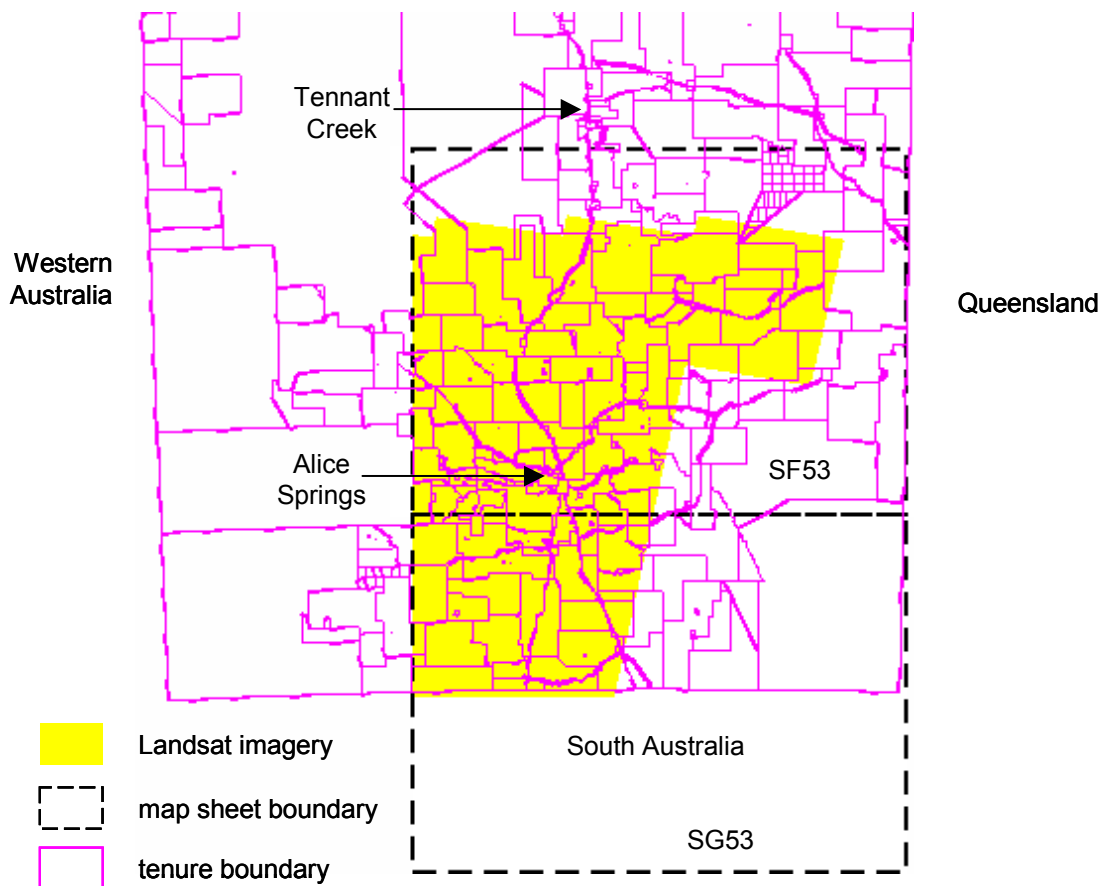


Figure A1.1: Location of analysis area in the southern NT

2.2 Landsat satellite imagery

Landsat satellite images were supplied to CSIRO by the AGO as part of earlier thresholding work to map change in forest extent. (Note that Australia-wide imagery compiled by the AGO is now available for purchase through Geoscience Australia, see web link above). Available coverage varied through time for the two 1:1,000,000 map sheets (SF53 & SG53) – from complete coverage in 2000 and 2002, to approximately that shown in Figure A1.1 for the earliest Landsat multi-spectral scanner (MSS) images (due to the different orbital paths of Landsat satellites prior to Landsat 5). For consistency in analysis through time, I selected the largest area of most commonly available imagery – as shown in Figure A1.1.

Image dates (epochs) acquired by the AGO varied depending on cloud cover, availability of imagery, etc, but generally conformed with the summarised data shown in Table A1.1.

Table A1.1: Details of Landsat image dates used for cover analysis

Epoch	SF53		SG53	
	most common date	date range in map sheet	most common date	date range in map sheet
1972	Nov 1972	Aug 1972 – May 1973	Dec 1972	Nov 1972 – Mar 1973
1980	June 1980	Dec 1979 – July 1980	Dec 1979	Oct 1979 – June 1980
1985	Jan 1985	Dec 1984 – Feb 1985	Jan 1985	January 1985
1988	Jan 1988	Dec 1987 – Mar 1988	Feb 1988	February 1988
1989	Dec 1989	Sep 1989 – Dec 1989	Oct 1989	Sep 1989 – Oct 1989
1991	Dec 1990	Dec 1990 – June 1991	Jan 1991	Dec 1990 – April 1991
1992	Feb 1992	Jan 1992 – June 1992	Jan 1992	Jan 1992 – Feb 1992
1995	Dec 1994	Nov 1994 – Jan 1995	Dec 1994	December 1994
1998	Feb 1998	Jan 1998 – March 1998	Jan 1998	Jan 1998 – Feb 1998
2000	Dec 1999	July 1999 – Jan 2000	Dec 1999	Sep 1999 – Dec 1999
2002	Mar 2002	Dec 2001 – Sep 2002	Mar 2002	Jan 2002 – March 2002

Note: Shaded years in the Epoch column represent Landsat MSS imagery, the remainder Landsat TM.

All images had been rectified to the Australian Map Grid (GDA 94) and radiometrically standardised to the Year 2000 image mosaic using spectrally invariant targets and robust regression techniques (see Furby 2002 for details). Landsat MSS imagery had a pixel size of 50 m; Landsat thematic mapper (TM) pixels were 25 m.

Masking

Areas of cloud, cloud shadow, smoke haze and other contaminated data (particularly ‘dropout’ in earlier image dates) were digitised and set to null values. (Note that this masking for the SF53 map sheet had been rigorously done earlier as part of AGO thresholding contracts. Due to time constraints with this project, digitising of contaminated data was performed less rigorously for the northern half of the SG53 map sheet. In particular, only the larger areas of more obvious ‘dropout’ were removed from the 1972 image.)

Vegetation cover index

Apart from a small area of ‘downs’ country (Mitchell grass, *Astrelba* spp.) on cracking grey clay soils in the far north-east of the region, the background soil colour is predominantly reddish brown with brighter coloured calcareous loams and alluvial sands in some areas. Experience has shown that the PD54 index (Pickup et al. 1993) calculated from the bandwidths of Landsat data corresponding with the visible green and red wavelengths provides a good indicator of vegetation cover on these predominantly red soils. PD54 parameters describing the ‘soil line’ and perpendicular point of maximum vegetation cover were calculated with ER Mapper and CSIRO software (see Bastin *et al.* 1998 for processing details). There were similarities in parameter values between years (epochs) due in large part to the

robust techniques used to radiometrically calibrate multitemporal imagery. Where possible, the separate parameters (slope and intercept of the soil line, and perpendicular distance to point of maximum vegetation cover) were grouped to similar sets of values (tabulated in Appendix 2a).

PD54 images of cover were calculated using the Gain, Offset and Distance parameters under the 'Values to Use' columns in Appendix 2a. These images were then linearly transformed to approximate percentage cover by viewing each PD54 image in a geolinked display with its corresponding false-colour composite, and determining the threshold values corresponding with bare ground (0% cover) and maximum cover (close to 100% cover). These values across the majority of image dates were PD54 = 60 for bare ground and PD54 = 230 for ~100% cover, producing the linear transform (in ER Mapper) of:

if input1 $\leq$ 60 then 0 else if input1 $\geq$ 230 then null else input1*0.588-35.294

2.3 Stratification layers

Land systems

Land Systems of the Alice Springs Area (Perry et al. 1962) was used as the land-type stratification regime to examine cover change over time. Some analyses were also based on land systems grouped into pasture lands (Perry 1961). Brief descriptions of land systems and their areas within the analysis region are provided in Appendix 2b.

Paddocks and pastoral leases

Fence line locations were obtained as vectors from the NT Department of Natural Resources, Environment and the Arts. These vectors were added to digitised polygons surrounding mountain ranges (i.e. natural barriers to cattle movement) to form enclosed paddocks. Each paddock was then identified to its relevant pastoral lease (or where appropriate, Aboriginal Land Trust area). Some leases surrounded by desert are unfenced, and in these cases it was necessary to form an arbitrary polygon (paddock) corresponding with the lease boundary to calculate distance from water (next section). The number of paddocks and their combined area in different size-class thresholds are listed in Table A1.2. Note that paddocks on pastoral leases exclude mountain ranges, conservation reserves and some areas of Aboriginal held land (Figure A1.2).

Table A1.2: Numbers and combined areas of paddocks above different size thresholds in the analysis area

	All paddocks	Paddocks $\geq$ 10 km²	Paddocks $\geq$ 50 km²
Number	2065	619	331
Combined area (km ²)	162 154	160 747	139 701

Note: these figures include parts of some paddocks contained within, but extending beyond, the area of common Landsat imagery shown in Figure A1.1

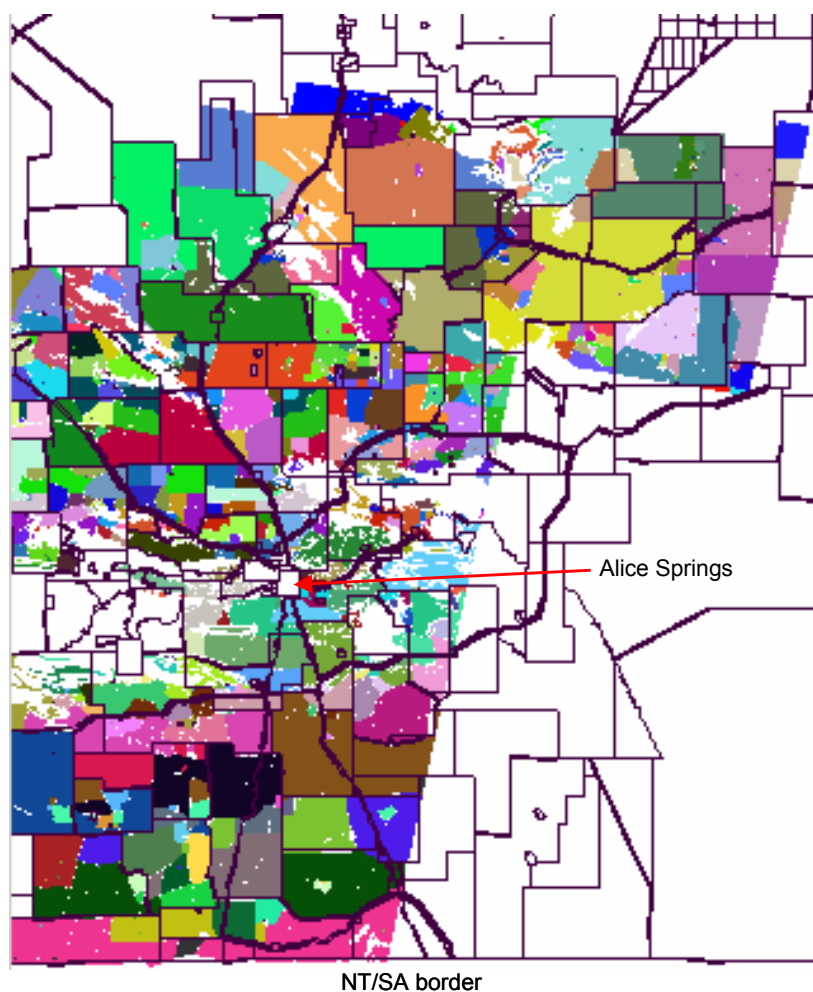


Figure A1.2: Representation of the 2000+ paddocks in the analysis area

Note: lines show pastoral lease boundaries and former stock routes.

Distance from water

In most grazed landscapes, grazing effects tend to be greatest closer to water – the piosphere effect (Lange 1969; see also Pickup and Chewings 1988, Bastin, Chewings et al. 1993; Bastin, Sparrow et al 1993 for grazing gradient results in central Australia). We calculated distance from water at 100 m increments for paddocks shown in Figure A1.2. To simplify analyses, distance-from-water was simplified to two classes (Figure A1.3):

1. 0–3 km – where grazing effects on cover derived from Landsat data was likely to be greatest
2. beyond 3 km from water.

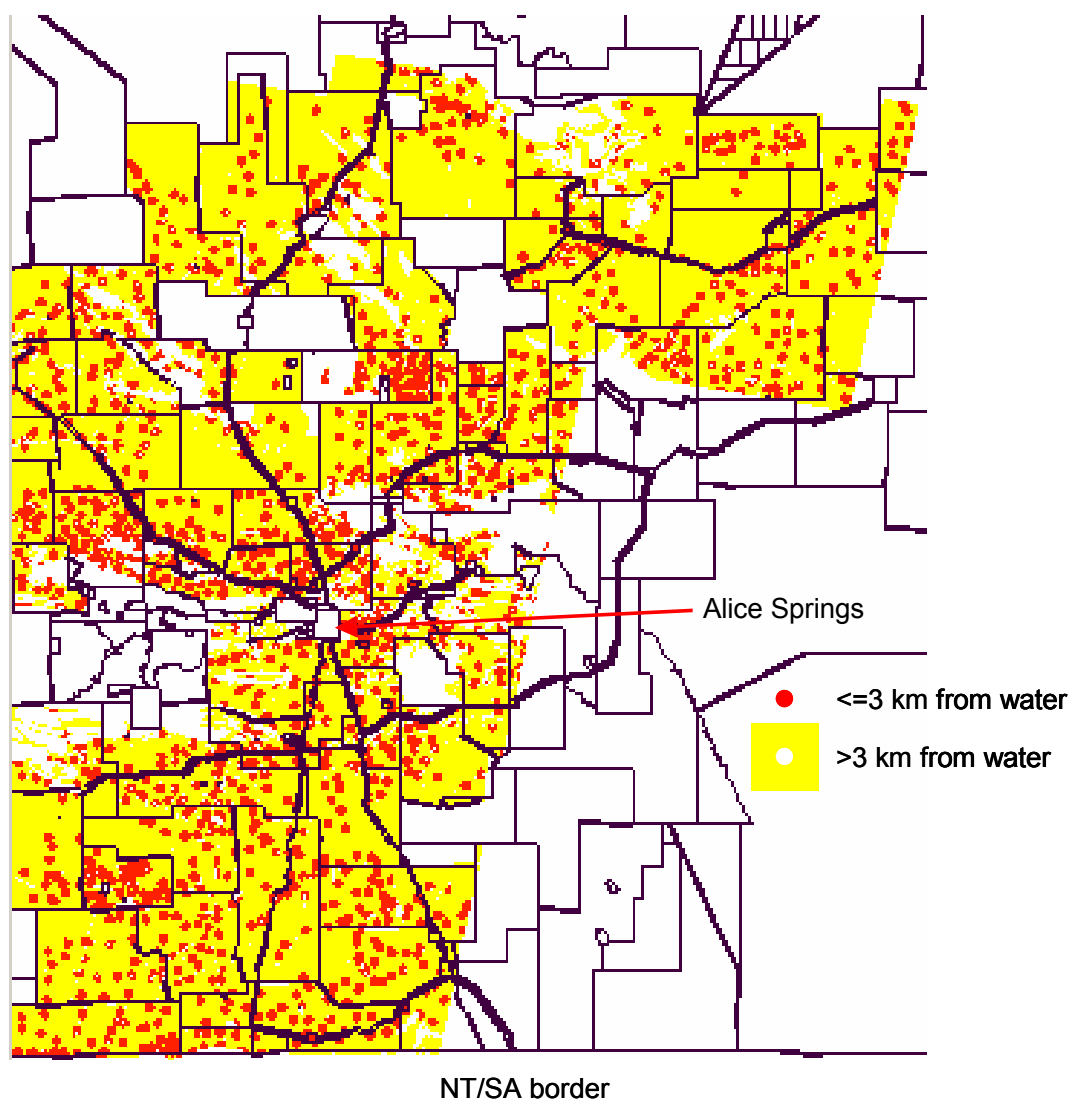


Figure A1.3. Areas within 3 km of water and beyond 3 km in the analysis area

Note: lines show pastoral lease boundaries and former stock routes.

2.4 Analysis procedure

Analysis was conducted in the following order:

1. Exploratory analysis of cover levels (by land system and pasture land group, Appendix 2c) for each year of imagery (i.e. epoch). Relate cover levels to preceding rainfall, as the expected main driver of cover variation.
2. Calculate mean and standard deviation of cover by land system for each time period.
3. Categorise departures from the 'global' mean cover for larger areas of each land system in larger paddocks. Analyses were made for areas of each land system >20 km² in paddocks >50 km². These restrictions were imposed to constrain the number of analyses and interpretations (from Table A1.2 there are 331 paddocks >50 km²). Separate analyses were made for areas within 3 km of water and beyond 3 km (Figure A1.3). For each analysis (i.e. land system by distance-from-water category by paddock), the paddock component scored:

Table A1.3: Paddock component scores

Score	Condition
1	mean cover was greater than one-half of the standard deviation above the 'global' mean for that land system – i.e. land systems within paddocks with generally higher cover for that time period.
2	mean cover was within one-half standard deviation of the 'global' mean for that land system – i.e. land systems within paddocks with around average cover for that time period.
3	mean cover was greater than one-half of the standard deviation below the 'global' mean for that land system – i.e. land systems within paddocks with generally lower cover for that time period.

The intent here is to identify those paddocks with land systems that, for the most part through time, have cover at a specified threshold either above or below the average for that land system. This procedure may constitute a suitable criterion for a cover-based component of an EMS, that is where outliers from the district norm are deemed to indicate either acceptable or unacceptable levels of grazing practice. (This approach is notional and requires much more rigorous testing – both to ensure that it accounts suitably for local variability in terms of seasonal rainfalls and landscapes, and that the thresholds that define 'acceptable' and 'unacceptable' grazing management practices are appropriate.)

It should be recognised here that while generally higher levels of cover (or cover above a critical threshold) may be desirable for dust suppression and minimising wind erosion risk, it is not always desirable for optimal pastoral production. Some land systems, and more precisely, *parts* of some land systems are prone to woody thickening such that density (and cover) of woody species suppresses pasture growth. Unfortunately, it is not easy to partition woody from other forms of cover with the PD54 index. Nor is it feasible in this regional analysis to subdivide land systems into those units which are more likely to show woody thickening. Rather, I have added a fourth stratification to the analysis.

4. Interpret changes within groups of land systems that are likely to show:
 - Cover likely to decrease with inappropriate grazing (taking account of prior seasonal conditions)
 - Cover likely to increase because of woody thickening (related to grazing and probable fire suppression), again considering prior rainfall
 - Variable cover response largely because of fire – the 'desert' land systems growing predominantly spinifex.
5. The spatial locations of scores from number 3 above are mapped back to an image.

2.5 Land condition index

The analysis procedure described above is interpreted as possible indicators of land condition in Table A1.4. Land condition is indicated in two ways:

1. Possible (probable) implications for long-term sustainable pastoral production
2. Possible (probable?) risk of enhanced dust generation because of reduced cover.

This land condition framework is exploratory and requires much more development and testing. It has a number of problems (elaborated further in the Results and Discussion section) including:

- Land system mapping is a relatively coarse way of stratifying land types. Many land systems include land units where cover will typically decrease with inappropriate grazing and others where cover may increase through woody thickening due to fire suppression and reduced pasture competition from grazing. Thus, averaging cover across land systems within paddocks may provide a misleading picture of what is happening in different parts of many land systems.

- Land systems have inherently different levels of mean cover. The implications for dust generation (i.e. inferred land condition indicator) will be different for a land system with Score 3 (i.e. mean cover > than ½ SD below global mean) where the land system has naturally low levels of cover compared with one that has inherently much higher cover.
- Similarly, land systems prone to woody thickening may score 3 for two different reasons:
 - cover is below the regional average because management has used fire to thin tree and shrub cover or
 - heavy grazing has reduced ground cover while woody cover has thickened. (There are obviously additional permutations between 1 & 2.)

Score 3 resulting from either scenario may not particularly matter for the dust land condition indicator (i.e. minimal risk of increased dust generation) but does imply two different condition results for sustained grazing (with scenario 1 the preferred option). (This problem would be reduced where remote sensing allowed partitioning of ground cover from woody cover, which is not possible here.)

- Cover varies with season (rainfall). Regional variation in rainfall may produce cover differences for land systems in some paddocks (translating to condition scores) that are more related to season than to grazing. I discount this effect later in the results section by focusing on predominant scores through the 30-year analysis period rather than using individual-year results.

Table A1.4: Analysis procedure interpreted in terms of possible indicators of land condition

Paddock Score	How derived	Response type		
		Cover likely to decrease with inappropriate grazing	Cover likely to increase because of woody thickening (related to grazing and probable fire suppression)	Variable cover response largely because of fire ('desert' land systems growing mainly spinifex)
1	Mean cover > than ½ SD above global mean for land system	<i>Good condition – minimal risk of dust generation related to grazing</i> Good condition – grazing practices appear to be maintaining good cover	<i>Good condition – minimal risk of dust generation related to grazing</i> Condition uncertain – where cover predominantly herbage (pasture), then condition good; where cover mainly woody, then condition reduced because less forage available for grazing and reduced opportunities to burn	<i>Good condition – minimal risk of dust generation related to grazing</i> Probable good condition – 'desert' land systems have low grazing value and are generally resilient to grazing pressure experienced
2	Mean cover within ½ SD of global mean for land system	<i>Satisfactory condition – low risk of dust generation related to grazing</i> Satisfactory condition – grazing practices contributing to maintenance of average cover	<i>Satisfactory condition – low risk of dust generation related to grazing</i> Satisfactory condition – management practices contributing to maintenance of average cover	<i>Good condition – minimal risk of dust generation related to grazing</i> Probable good condition – 'desert' land systems have low grazing value and are generally resilient to grazing pressure experienced
3	Mean cover > than ½ SD below global mean for land system	<i>Poor condition – increased risk of dust generation (particularly for land systems with lower levels of mean cover and those with loamy and sandy soils)</i> Reduced condition – grazing practices may be contributing to reduced forage availability	<i>Satisfactory or poor condition – satisfactory where land systems have moderate and higher levels of cover; increased risk of dust generation off land systems with inherently lower cover and hence reduced condition</i> Condition uncertain – where management practices have reduced woody thickening, then good condition; where cover is lower because grazing has removed ground cover (and woody thickening has likely occurred), then poor condition	<i>Satisfactory condition – cover generally re-establishes quickly after fire. There is increased risk of dust generation where dry years follow extensive wildfire – particularly in the Simpson Desert and its margins (Simpson land system)</i> Probable good condition – 'desert' land systems have low grazing value and are generally resilient to grazing pressure experienced

Note: Italicised font describes possible implications for dust generation (i.e. risk). Non-italicised font describes possible implications for sustained pastoral production.

3. Results and discussion

3.1 Cover images

The sequence of images showing approximate percentage cover through time is shown in Figure A1.4. Note that I have not attempted to validate the accuracy of estimated cover values (but previous ground truthing has shown the PD54 index to be reasonably accurate in central Australia, see Pickup et al. 2000). These images depict a large area (almost 600 km north-south, ~250 km east-west at the NT-SA border in the far south) and a more detailed view of seasonal variation in cover can be seen in the 20 km by 20 km area centred on Kunoth Paddock, approximately 35 km north-west of Alice Springs (Figure A1.5).

Features of Figures A1.4 and A1.5 include:

- As noted above, the considerable year-to-year differences in cover – e.g. highest cover in 2002 and then 1980, lowest cover (in parts) in 1972, 1988, 1992 and 2000.
- Regional differences in cover in particular years (Figure A1.4) – some of these are due to image-date differences. For example, the north-eastern image of 1985 was acquired on 13th January 1985, six weeks before the adjacent image to the west (21 February 1985). It appears that some rain may have fallen in this time. Much of the country in this north-eastern image is spinifex sandplain and the lower cover levels at this time could be due to recent extensive wildfire.
- The regional differences described above carry through to the smaller area shown in Figure A1.5 where landscape structure is clearly visible. Cover was consistently higher on mulga shrublands (eastern and northern parts of each image) and the Chewings Range (south), and lowest on the floodplains (centre of image area extending to the west).
- Over time, highest cover was recorded in 2002. Cover was also high in the eastern half of the image area in 1980, and a little lower in this area in 1985, 1989 and 1995 (Figure A1.5). On the more open country (central and western portions), cover was lowest in 1992, 1988, 2000 and 1972.
- Some image boundary effects are apparent through time – the slanting line in the western third of the 1985, 1989 and 1998 images (Figure A1.5). The vertical line visible in the far right of most images from 1980 onwards is the Bond Springs–Hamilton Downs boundary where a wildfire on Bond Springs in 1976 killed much of the mulga and other shrubs. This fenceline effect appears to be dissipating with time as re-establishing shrubs increase in size and density.

3.2 Cover change and likely influence of rainfall

We know that levels of total vegetation cover are very much affected by rainfall. Vegetation indices are also sensitive to vegetation greenness, or photosynthetic activity, although the PD54 index is less sensitive to changing phenology than some other indices (Pickup et al. 1993).

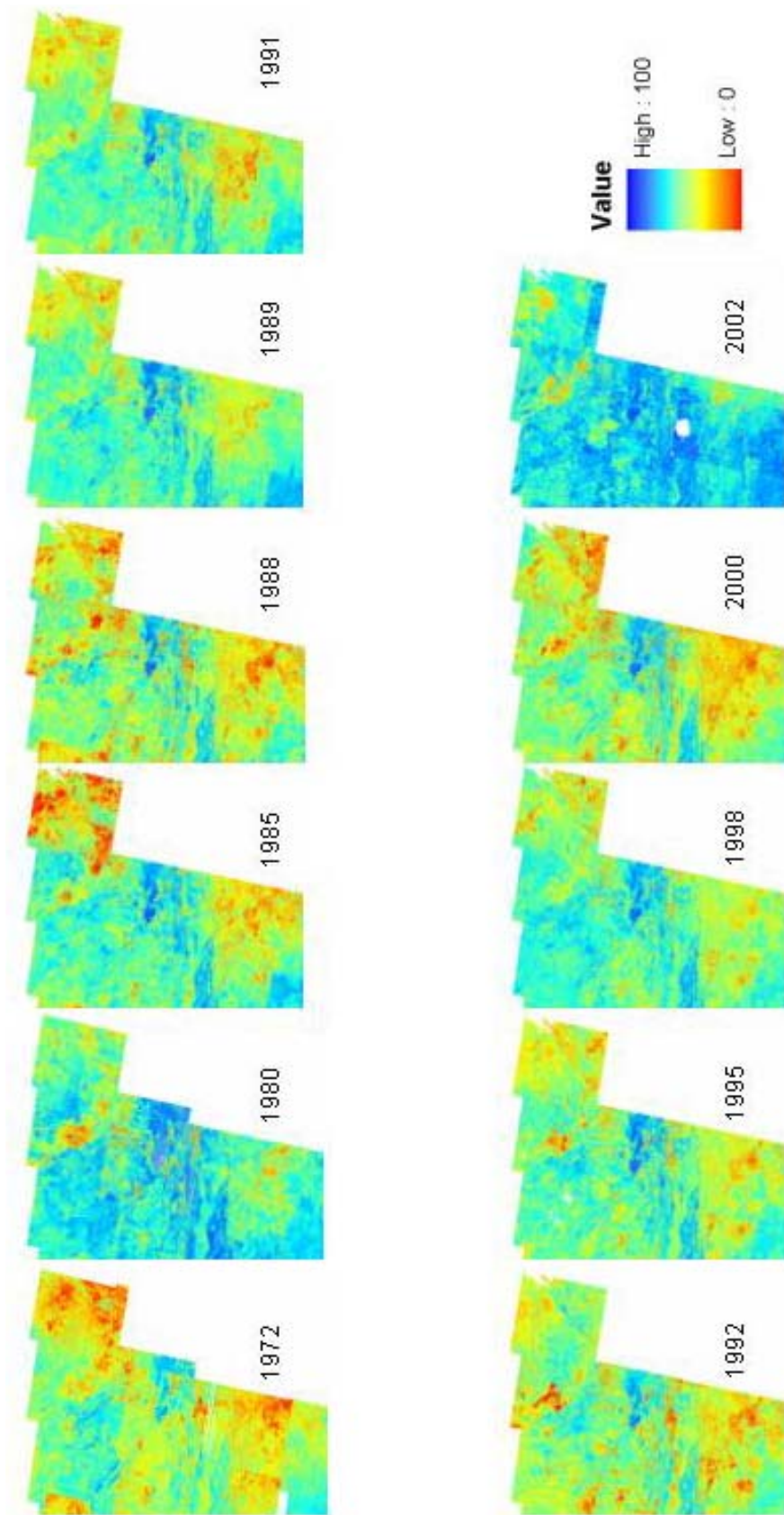


Figure A1.4: Sequence of cover change images through time (complete analysis area) based on linear rescaling of PD54 values to approximate percentage cover

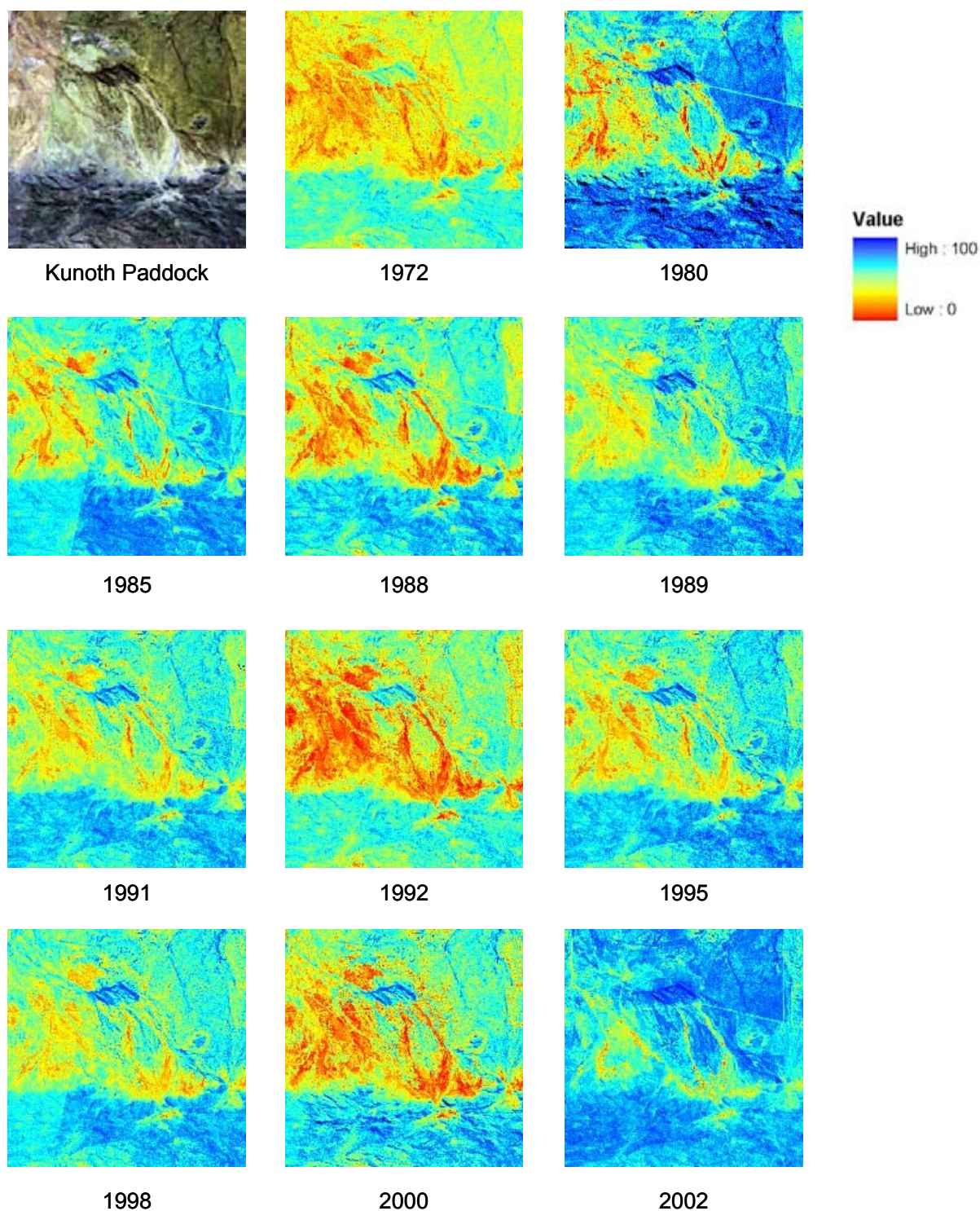
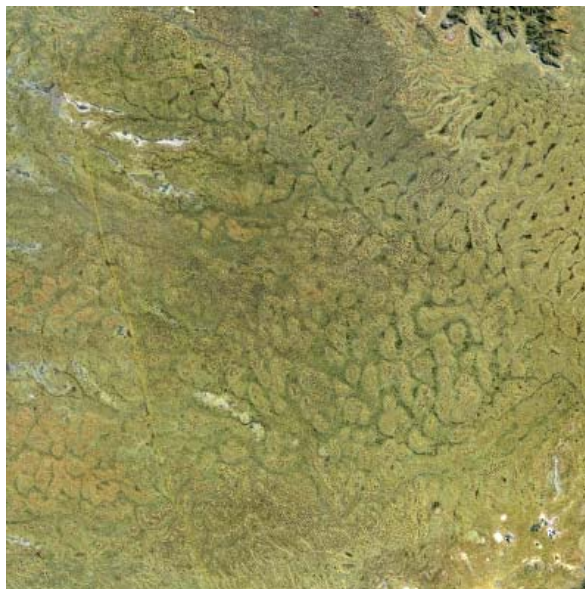


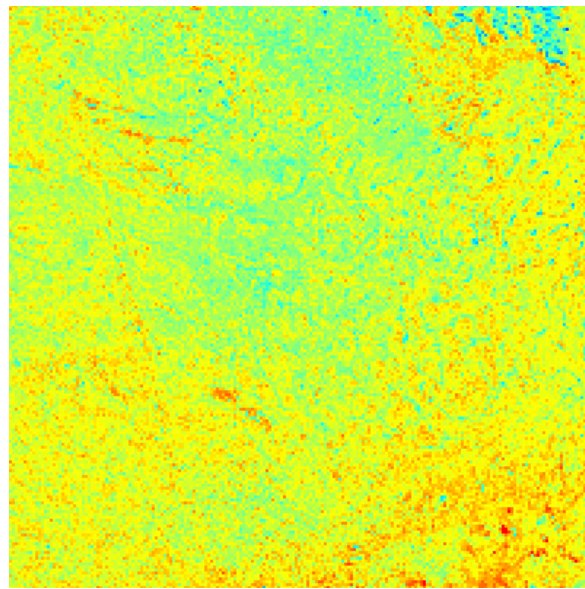
Figure A1.5: Sequence of cover change images through time for the 20 km by 20 km area encompassing Kunoth Paddock, approximately 35 km north west of Alice Springs

Note: cover estimated by linearly rescaling PD54 values to approximate percentage cover.

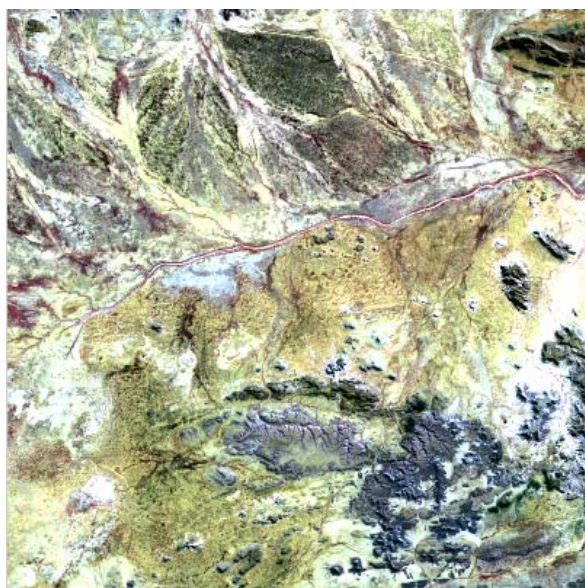
To more closely examine cover variation through time, and the possible effects of prior rainfall amounts on cover levels at the time of image acquisition, I selected two areas of contrasting land types within 50 km of the Alice Springs airport (and Bureau of Meteorology office). Each area is 400 km² (20 km by 20 km), one is a reasonably uniform area of sandplain and dune country with predominantly spinifex, the other is a much more diverse area of alluvial plains adjacent to the Todd River (Figure A1.6). The second area also includes small areas of hill country in the north east and south east.



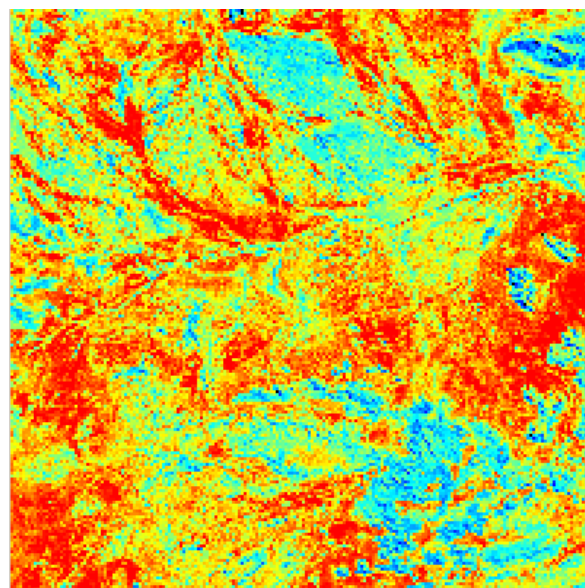
Sandplain and dunes (TM bands 2, 3 & 4)



Sandplain and dunes – PD54 cover index



Alluvial plains (TM bands 2, 3 & 4)

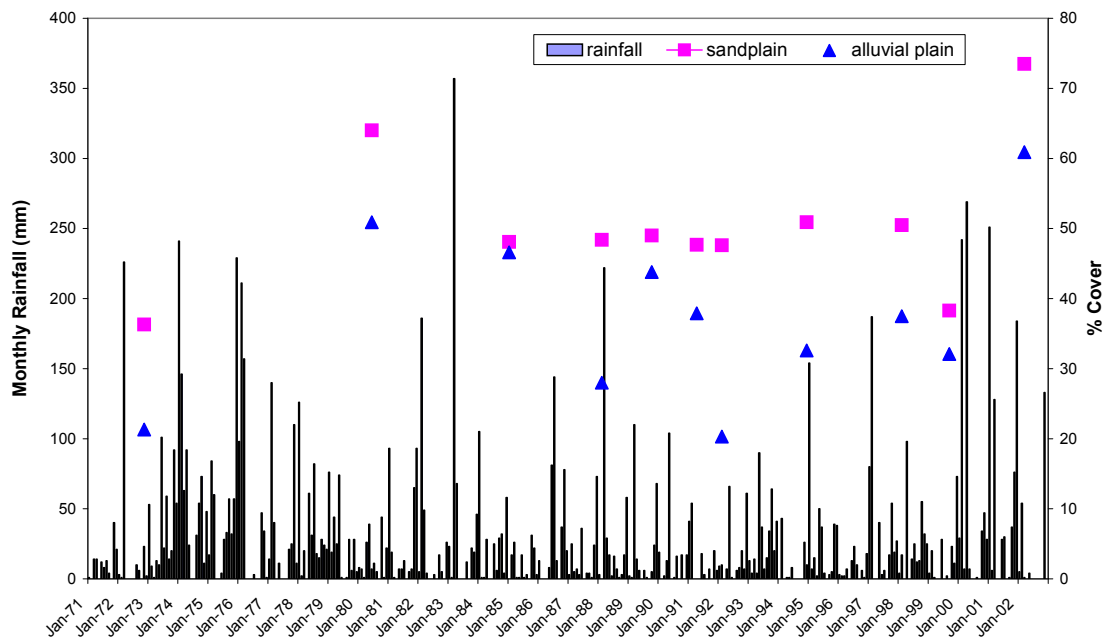


Alluvial plains – PD54 cover index

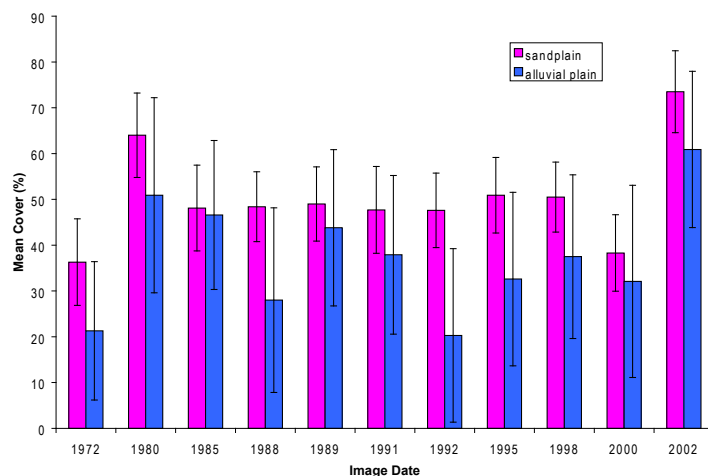
Figure A1.6: Areas of sandplain–dune country and alluvial plains selected to examine rainfall amounts on cover levels

Note: Images shown are for the 2000 image date (acquired September 1999). PD54 cover levels are as per the legend in Figs. 4 & 5.

Changes in the mean level of cover over time were much more variable on the selected area of alluvial plain than sandplain and dunes (Figure A1.7a). The alluvial plains area also had much higher variability in cover (Figure A1.7b) related to the spatial complexity and patterning of this area (shown in the lower panels of Figure A1.6).



(a)



(b)

Figure A1.7:
 (a) monthly rainfall recorded at the Alice Springs Bureau of Meteorology Office and mean cover levels for the sandplain and alluvial plain test areas
 (b) mean and standard deviation of cover for example areas

Features apparent from Figure A1.7:

- Mean cover on the sandplain – dune area was always above that on the alluvial plain area – but only just at the times of the January 1985, October 1989 and September 1999 (equal 2000 epoch) image acquisitions.
- As noted above, variability of cover on the alluvial plain area was always much greater than that on the sandplain – dune area. This is due to the distinct landscape patterning (i.e. much greater spatial variability) on this area.
- In terms of rainfall prior to image acquisition:
 - There was low cover on the alluvial plain area and moderate cover on the sandplain–dune area at the time of the first available image (November 1972). Cover levels at this time were probably influenced by the large rainfall event of 226 mm in March 1972. This was the only large rainfall event up to that time in the 1970s; prior significant (or growth producing) monthly rainfalls were in the order of 50 mm in April and December 1970 and November 1971. Vegetation cover was likely still re-establishing after the extended 1958–65 drought,

and long-term photo sites indicate that there was appreciably less tree and shrub cover then compared with now (Cunningham 1996). Conditions were dry in the eight months from March to November 1972 so that cover levels indicated by the 1972 image may have been lower than that present shortly after the March rainfall due to disappearance of ephemeral herbage, more particularly on the alluvial plains area.

- Cover levels reached their second highest level of the recorded 30-year period in June 1980, but Figure A1.7a shows there were no large rainfalls prior to the 1980 image being acquired. Rather, the example areas probably depict accumulated cover resulting from the extended wet period of 1974–76, with further growth-producing rainfalls also being experienced between 1977 and 1979.
- The January 1985 image was acquired twelve months after the previous significant growth-producing rainfall, although some pasture growth should have resulted from the 58 mm in December 1984. It is probable that there was significant carry-over of cover from the very large rainfall in March 1983.
- The February 1988 image indicates cover levels towards the end of a drier period between January 1984 and March 1988. The large rainfall event in June and July 1986 grew winter herbage that contributed little to more persistent cover. Cover levels were maintained at a near-constant level through the later 1980s and the 1990s on the example area of sandplain and dunes, but fluctuated considerably on the alluvial plain area – probably due to the combined effects of grazing, trampling and disintegration/disappearance of more ephemeral cover.
- Cover levels increased on the alluvial plain area in October 1989 (compared with February 1988) due to the large rainfall in March 1988 and smaller falls in December 1988 and March 1989. Cover then declined by April 1991 with dry conditions through the preceding summer, and declined much further by February 1992 with continuing low monthly rainfall.
- The improvement in cover shown by the December 1994 image appears anomalous as it precedes substantial rainfall in January 1995. The normalised difference vegetation index (NDVI) produced from the 1994 image does not show any areas of green vegetation that may have resulted from isolated storms that may have fallen in the area but were not recorded at the Bureau of Meteorology office. Rather, comparison of the false colour composite and PD54 images shows that cover increased on sandy fans and plains between 1992 and 1995 – with this cover increase most likely attributable to growth of woody species.
- Mean cover had increased a little further in February 1998 on the alluvial plain area with this image acquisition being 12 months after substantial rainfall in February 1997. There may have been some persistence of pasture (ground) cover through this period but the false colour and PD54 cover images show that the sandier areas were holding or improving their cover level through this period – again suggesting that woody species were the main component of cover, and likely contributing to the small increase in mean cover.
- Mean cover decreased slightly on the alluvial plain area and substantially on the sandplain and dune area in the September 1999 image. There is no evidence of any recent fire contributing to this decline, so cover decrease likely resulted from continuing dry conditions in the late 1990s (i.e. decay) and cumulative grazing effects in this ‘desert’ country.
- Cover increased dramatically on both areas by March 2002 following the extended wet period between February 2000 and December 2001.

In summary, some recorded (and indicated) levels of high cover were directly related to prior rainfall (particularly March 2002, probably January 1985). Others result from an extended wet period in previous years (June 1980). At other times, cover (particularly on the alluvial plain area) showed the effect of reduced rainfall, probably combined with the cumulative effects of grazing and trampling. In

December 1994, February 1998 and September 1999, under generally dry conditions, mean cover levels on the alluvial plain area appeared to be buffered by slowly increasing woody cover on fans and plains with sandier soils.

In the following sections of results and associated discussion, prior rainfall (or lack of it) is identified as a contributor to cover levels as presented. Because of spatial variability in rainfall and its variable effects on resultant vegetation cover (dependent on soil/vegetation type and land condition), it is not possible to isolate seasonal effects and attribute paddock differences directly to recent or longer-term grazing management. Fire (generally wildfire) also contributes to indicated cover levels on parts of the less productive ('desert') grazing country.

3.2 Mean cover by land system

Initial examination of cover levels for land systems grouped into pasture lands (Appendix 2b) showed that there were relatively small differences in mean cover among pasture lands at each image date accompanied by fairly large standard deviations. The small differences in mean values and large variance (i.e. standard deviation) were attributed to high spatial variability in cover contributed by differences in land and vegetation type and probable differences in rainfall across the very extensive areas of some pasture lands. Most land systems are confined to a geographic location within the region although some, such as Singleton (spinifex sandplain) and Bushy Park and Boen land systems (mulga shrublands), are more widespread. For the more spatially confined land systems, there should be reduced effect of regional rainfall differences on variation in vegetation cover. For most land systems, there will still be moderate spatial variation in cover due to differences among component land units. As indicated above, it was not feasible to stratify beyond land system level in this regional examination of cover change through time.

The mean cover of each land system derived from each image date is listed in Appendix 2c (refer to Appendix 2b for land system areas). Examples of cover change through time for a high-cover land system (Bushy Park, mulga shrubland) and low-cover land system (Ebenezer, bluebush and shrubby grassland on calcareous plains) are shown in Figure A1.8.

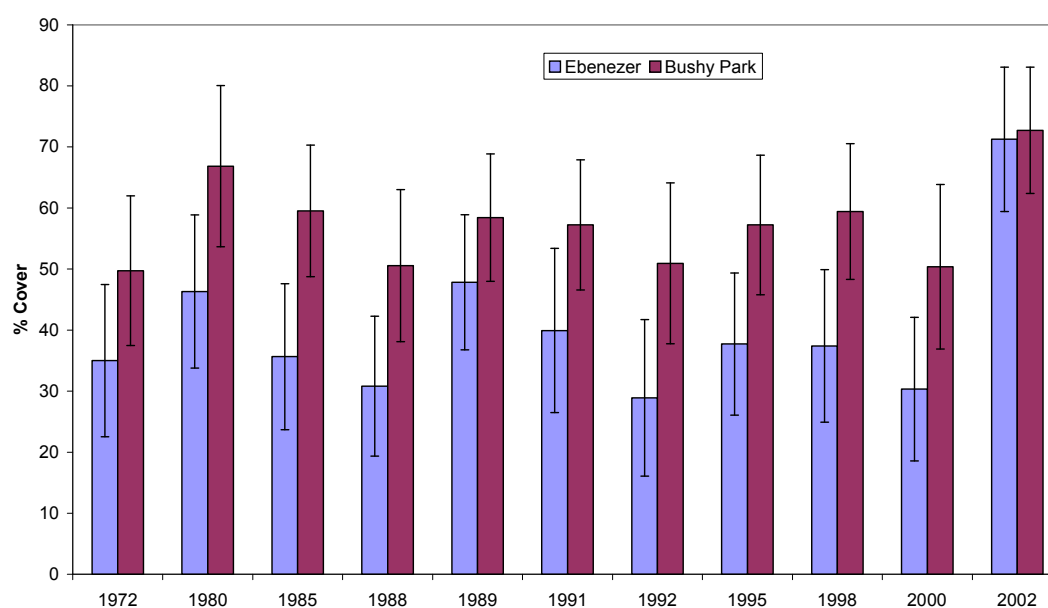


Figure A1.8: Mean and standard deviation of cover between 1972 and 2002 for the Bushy Park and Ebenezer land systems

Cover on the more open calcareous Ebenezer land system was always less than that on the mulga shrubland Bushy Park land system except in the most recent wettest period (2002). The differences were most marked in drier years – 1985, 1988 and through the 1990s to 2000.

- Mean cover on Bushy Park land system was more stable than on Ebenezer land system. Persistent cover provided by trees and shrubs buffers against seasonal variation in cover due to rainfall variability.
- Ebenezer land system is present in the far south of the region and Bushy Park land system occurs north of Alice Springs, and so tends to receive more rainfall. However, rainfall patterns are occasionally counter to this pattern – for example, the southern Alice Springs region received high rainfall in March 1989 (361 mm at Erldunda) and areas north of Alice Springs were much drier. Thus in October 1989, mean cover on Ebenezer land system approached that of Bushy Park land system.
- Variability of cover within years was a little less on Bushy Park land system compared with Ebenezer land system, although it was still substantial on both.

3.3 Categories of cover within paddocks

Paddocks form the principal unit of management in the rangelands with pastoralists deciding what numbers and type of animal to graze and how long to graze each paddock based on the assessed quantity and quality of forage. Some pastoral leases in central Australia still remain largely unfenced, and individual (or groups of) waters provide the basis for stock and grazing land management. Most paddocks in the analysis region contain a mix of land types, with cattle displaying a different grazing preference for each – e.g. calcareous grasslands and alluvial plains grazed in preference to mulga shrublands or spinifex sandplain. Regional land system mapping (Perry et al. 1962) provides a coarse level of land type stratification and is used here for convenience. However, mapped polygons often lack the spatial detail to identify levels of grazing use and probable longer-term responses to grazing. For example, Hamilton land system describing alluvial plains below the Chewings Range north-west of Alice Springs includes largely treeless plains which occasionally flood, adjacent sandy loam plains of older alluvial origin with open woodlands and much older red-earth sediments with mulga shrublands. Cattle preferentially graze more nutritious grasses and forbs on the younger and more fertile sediments and minimally use the mulga country until forage becomes limited on the ‘sweeter’ country (Low et al. 1981). The more open floodplain and woodland country is likely to show a substantial decrease in cover as a result of excessive grazing while the mulga shrublands may show cover increase due to thickening of mulga and other shrubs. (The woodland country may also suffer woody thickening as well.)

Accepting the limitations of land system mapping for suitably stratifying land types to identify recent (and perhaps longer term) grazing effects, I have grouped them into the three categories described in the Methods section for subsequent reporting of cover change in paddocks (categories re-described below):

- Land systems likely to show a decrease in cover with heavy grazing
- Land systems where cover is likely to increase due to woody thickening resulting from fire suppression – likely to be allied with longer-term heavy grazing because of reduced fuel loads following wet years, and hence reduced opportunities to burn, and reduced competition for trees and shrubs from pasture species
- Land systems where fire (both wild and managed) is an important cause of cover change – mainly land systems with spinifex-dominance.

For each land system grouping, I report the number of paddocks at each image date where average cover is above, within or below the thresholds described in the Methods section. To constrain the analysis and reporting, I have restricted analyses to land systems with > 20 km² area in paddocks > 50 km² area.

Cover likely to decrease with heavy grazing

Component land systems are listed in Table A1.5. Note that, as explained above, land units within some land systems may show woody thickening (cover increase) over time. However, the land system is generally deemed to suffer a decrease in cover with excessive grazing pressure.

Table A1.5: Land systems that tend to show a decrease in cover with excessive or inappropriate grazing pressure

Pasture land	Land systems
Alternating hills and lowlands	Aileron, Allua, Bond Springs, Chisholm, Cavenagh, Rumbulara, Table Hill
Sparse low tree country	Alcoota, Anderinda, Barrow Creek, Dinkum, Ennugan, Indiana, Jinka, Ryan, Unca, Warburton
Mulga mixed with spinifex sandplain	Lindavale
Witchetty bush	Muller, Outounya
Gidgee	Delny, Lucy, Ooratippra, Pulya, Ringwood
Variable sparse low vegetation	Titra, Woolla
Short grass – young alluvia	Adnera, Ammaroo, Deering, Finke, Hamilton, Kanandra, McDills, McGrath, Sandover, Todd, Utopia, Woodduck
Bluebush	Ebenezer, Lilla, Renners
Saltbush	Endinda, Kalamerta, Kulgera, Peebles, Wilyunpa
Mitchell grass	Ambalindum, Undippa
Open country with <i>Sclerolaena</i> pastures	Chandlers
Spinifex	Angas

Cover levels with distance from water

The percentage (of the total number) of land system–paddock combinations that had average cover **above**, **within** or **below** one-half standard deviation of the overall mean for the relevant land system at each image date is summarised in Table A1.6. The actual numbers are graphed in Figure A1.9 to assist visual interpretation. (Note that analysis is restricted to land systems with > 20 km² area in paddocks > 50 km² area.)

The percentage of land system–paddock combinations in the ‘above’ category (i.e. mean cover greater than one-half standard deviation above the ‘global’ average for the land system) was consistently higher beyond 3 km from water compared with the area 0–3 km from water (but only just in 1989). This difference was most marked in years with higher cover (1980, 1985, 2002, i.e. wetter years), indicating that grazing effects (utilisation and possibly some trampling) were most marked closer to water. This is sensible because in years when forage should be abundant, most grazing would be occurring close to watering points.

Conversely, there was a consistently greater percentage of land system–paddock combinations with mean cover in the ‘below’ category closer to water (i.e. ≤3 km) compared with further from water.

Table A1.6: For land systems where cover tends to decrease with heavy grazing, the percentage of land system–paddock combinations, and total count, where mean cover was above, within or below one-half standard deviation of the relevant mean land system cover at each image date

Distance from water	Cover category	Image date										
		1972	1980	1985	1988	1989	1991	1992	1995	1998	2000	2002
≤3 km	Above	12.3	11.3	7.7	8.2	11.6	7.2	8.7	6.3	6.8	7.7	7.2
	Within	65.7	64.7	65.7	68.1	67.1	69.6	68.1	70.5	72.9	72.9	70.5
	Below	22.1	24.0	26.6	23.7	21.3	23.2	23.2	23.2	20.3	19.3	22.2
	Total	204.0	204.0	207.0	207.0	207.0	207.0	207.0	207.0	207.0	207.0	207.0
>3 km	Above	16.8	17.9	15.6	14.5	12.1	12.8	14.9	11.1	9.7	11.8	15.3
	Within	69.3	67.1	73.0	74.7	78.9	75.4	76.5	77.5	80.3	78.2	77.8
	Below	13.9	15.0	11.4	10.7	9.0	11.8	8.7	11.4	10.0	10.0	8.9
	Total	280.0	280.0	289.0	289.0	289.0	289.0	289.0	289.0	289.0	289.0	288.0

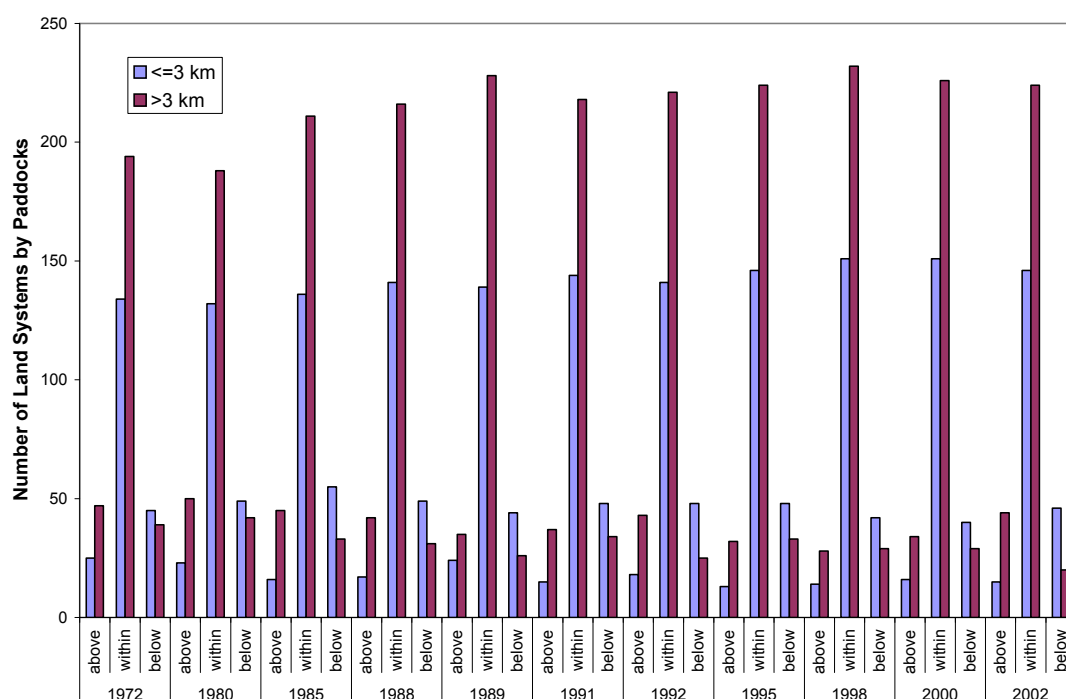


Figure A1.9: For land systems where cover tends to decrease with heavy grazing, the number of land system–paddock combinations where mean cover was above, within or below one-half standard deviation of the relevant mean land system cover at each image date

The consistency of cover categories for individual land system–paddock combinations through time is summarised in Table A1.7. Closer to water (0–3 km), a small number of land systems in paddocks had average cover consistently in the ‘below’ category (i.e. more than one-half standard deviation below the relevant land system ‘global’ mean). The number of paddocks was always greater than for the ‘beyond 3 km’ distance class. Conversely, slightly more land system–paddock combinations consistently scored in the ‘above’ cover category further from water compared with closer to water.

Table A1.7: For land systems where cover tends to decrease with heavy grazing, the number of land system–paddock combinations showing a consistent (or near-constant) pattern of cover category through time

Cover category	Number of occurrences (based on image dates)	Number of land system–paddock combinations	
		≤3 km from water	>3 km from water
Below	11 (out of 11)	6	0
	10 (out of 11)	4	1
	9 (out of 11)	11	5
Above	11 (out of 11)	1	2
	10 (out of 11)	2	6
	9 (out of 11)	4	7

Note: Cover categories are above, within or below one-half standard deviation of the relevant mean land system cover at each image date.

The majority of land system–paddock combinations for both distance-from-water classes had a shifting pattern of cover category through time, with most fluctuating between either the ‘below’ and ‘within’ categories (i.e. generally lower cover) or ‘within’ and ‘above’ (generally higher cover) – supported by the data in Table A1.8 below.

Although focusing on change in cover category between particular years only conveys part of the overall pattern of change, it is another way of condensing results. The major changes in status of land system–paddock combinations between the image dates of 1972 and 2000 (actually, 1999) is summarised in Table A1.8. (Note that I use 2000 in preference to 2002, the most recent available image date, because it better relates to the probable dry seasonal conditions prevailing at time of acquiring the 1972 imagery.)

Table A1.8: For land systems where cover tends to decrease with heavy grazing, the number of land system–paddock combinations showing either no change or substantial change in cover categories based on cover present in the 1972 and 2000 image dates

Distance from water category	Cover category combinations ¹ – number of land system–paddock combinations			
	Below – Below i.e. no change	Below – Above substantial change	Above – Below substantial change	Above – Above i.e. no change
≤3 km	21	1	0	10
>3 km	14	2	1	18

¹Based on cover category for each land system–paddock combination in the 1972 and 2000 image dates.

Land systems and stations

To summarise paddock by land system combinations of cover category through time, I selected those land systems by paddocks showing average cover levels predominantly above or below the global mean for each land system. Cover was ‘*predominantly above*’ if more than half of the 11 image dates had a mean cover for the land system–paddock combination greater than one-half of a standard deviation *above* the global mean for that land system. Similarly, cover was ‘*predominantly below*’ if more than half of the 11 image dates had a mean cover for the land system–paddock combination greater than one-half of a standard deviation *below* the global mean for that land system. The results are summarised by *station* in Table A1.9 and by *land system* in Table A1.10.

Closer to water (i.e. distance ≤3 km) across all stations, there was three times as many land system–paddock combinations showing ‘predominantly below’ average cover compared with ‘predominantly above’ average cover (Table A1.9). Further from water (>3 km), more land system–paddock combinations (in total) showed a ‘predominantly above’ average cover level than ‘predominantly below’.

Closer to water, Kanandra and Sandover land systems had the greatest number of paddocks showing cover predominantly below the respective overall mean through time (Table A1.10). Both land systems are members of the Short Grass on Young Alluvia pasture lands group. Further from water, Sandover land system had most paddocks with predominantly lower cover. Outounya, Kanandra and Chandlers land systems had the greatest number of paddocks with cover predominantly above the global land system means further from water (three for each land system). Closer to water, Outounya and Kanandra land systems each had three paddocks with predominantly higher cover.

Mapped land condition classes – cover decrease due to grazing

Land systems >20 km² in paddocks (>50 km²) showing a predominant pattern of cover above, below or within one-half standard deviation of the global mean for each land system throughout the reporting period are mapped in Figure A1.10. This mapping is for those land systems that tend to show cover decline with inappropriate grazing management (Table A1.5). ‘Predominant’ is defined as the dominant result in more than half of the available 11 image dates. Alice Springs, Jervois and Ali Curung meteorological stations are shown as reference points. LCI classes are also shown for the 1999 image (Figure A1.11), a recent dry year.

As explained earlier in this report, this land condition indicator is entirely exploratory at this stage and the mapped results (Figure A1.10) have not been validated in any way. One obvious comment is that the areas shown in red (cover > ½ SD below the global land system average) are generally small and dispersed (apart from a couple of larger areas in the far south) and would not seem to pose much of a dust generation hazard. If there is merit in the analysis approach used here, then it may be more valuable to focus on areas with below-average cover in the very dry years (subject to ready availability of suitable archival imagery) rather than mapping the predominant LCI score across an extended image sequence (as I have done here). It is probably also useful to explore the effect of adjusting the LCI thresholds (i.e. separate to +/- ½ SD of each land system mean). It is probably also desirable to include additional imagery of stations fringing the Simpson Desert, and the desert itself, as this area is probably a significant source of dust observed at Alice Springs and Jervois.

Table A1.9: For land systems where cover is likely to decrease with heavy grazing, the number of paddock by land system combinations on each station where mean cover was predominantly above or below the overall mean for that land system through time

Station	Distance from water ≤3 km		Distance from water >3 km		Total land system by paddock combinations
	Predominant paddock-by-land system cover category				
	Above	Below	Above	Below	
Aileron			2		2
Alcoota			1		1
Ambalindum		1			1
Ammaroo			1		1
Angas Downs		1	1	1	3
Anningie				1	1
Annitowa		2			2
Arapunya		2		2	4
Bond Springs				1	1
Bushy Park		1			1
Deep Well		1			1
Derry Downs				1	1
Elkedra		1		2	3
Erlunda		1			1
Glen Helen		2		1	3
Hamilton Downs	1	1	1		3
Henbury		2			2
Horseshoe Bend		2		1	3
Idracowra		2	2		4
Lilla Ck	1				1
Lucy Ck				1	1
Lyndavale	1		2		3
MacDonald Downs				1	1
Mt Cavenagh	1		2		3
Mt Denison		2			2
Mt Ebenezer		1		2	3
Mt Riddock	3	1	3		7
Mt Skinner			2		2
Murray Downs	1				1
Napperby	1	1		1	3
Narwietooma		3			3
Neutral Junction		1			1
Orange Ck			2		2
Palmer Valley		1			1
Pine Hill	1		1		2
Ringwood		1			1
The Garden		1			1
Todd River			2		2
Umbeara		6		3	9
Undoolya		1			1
Urrampinyu ALT			1		1
Victory Downs	3		2		5
Yambah		2			2
Total	13	40	25	18	96

Note: See the text for the description of 'predominantly above' and 'predominantly below'.

Table A1.10: For land systems where cover is likely to decrease with heavy grazing, the number of paddocks where mean cover was predominantly above or below the overall mean for that land system through time

Land system	Distance from water ≤3 km		Distance from water >3 km		Total number of paddocks
	Predominant cover category for paddocks through time				
	Above	Below	Above	Below	
Ambalindum		1			1
Alcoota	1	1		1	3
Adnera			1		1
Aileron			1		1
Allua			1		1
Ammaroo	1	1	1		3
Angas		1	2	1	4
Bond Springs		2			2
Chisholm		1	1		2
Chandlers		2	3		5
Cavenagh	1	1	1		3
Delny	1			1	2
Ebenezer		3	1	1	5
Endinda	1				1
Ennugan				1	1
Finke		1	1		2
Hamilton		1	1		2
Kalamerta		2		1	3
Kanandra	3	5	3	1	12
Lindavale	1	2	2	1	6
Lilla		1			1
McGrath			1		1
Outounya	3	3	3	2	11
Ringwood		1	1		2
Rumbulara		1		1	2
Sandover		7	1	5	13
Titra	1	1			2
Warburton		1			1
Woodduck		1		2	3
Total	13	40	25	18	96

Note: See the text for the description of 'predominantly above' and 'predominantly below'.

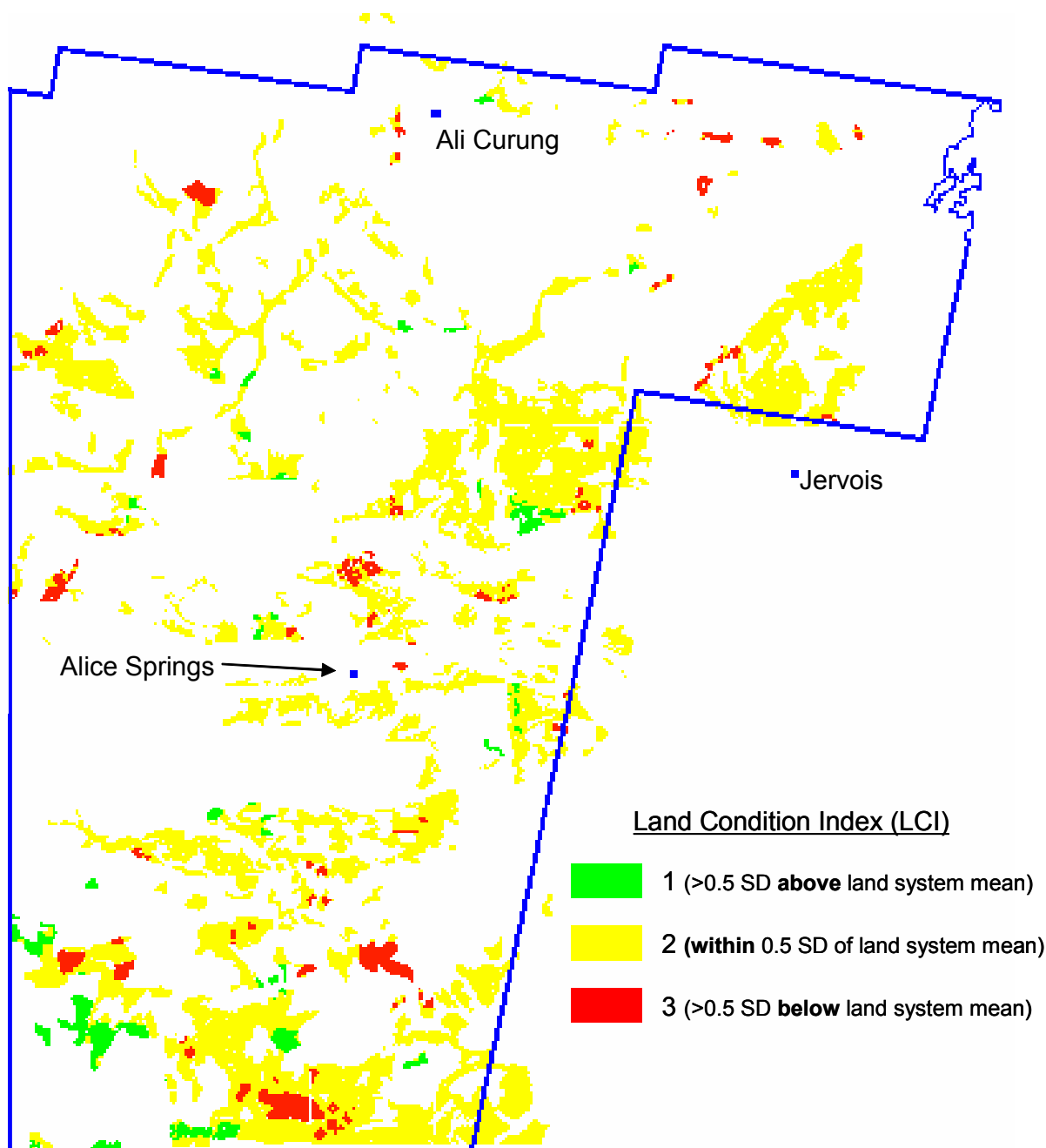


Figure A1.10: Predominant mapped land condition index values for land systems where cover tends to decrease with inappropriate grazing management

Notes: The blue polygon encloses the area of Landsat imagery common to all dates (i.e. area over which cover analyses conducted). The bottom of the image corresponds with the NT/SA border.

Alice Springs, Jervois and Ali Curung are shown for reference – these are the locations of meteorological stations with dust records.

'Predominant' is the dominant result from more than half of the available 11 image dates.

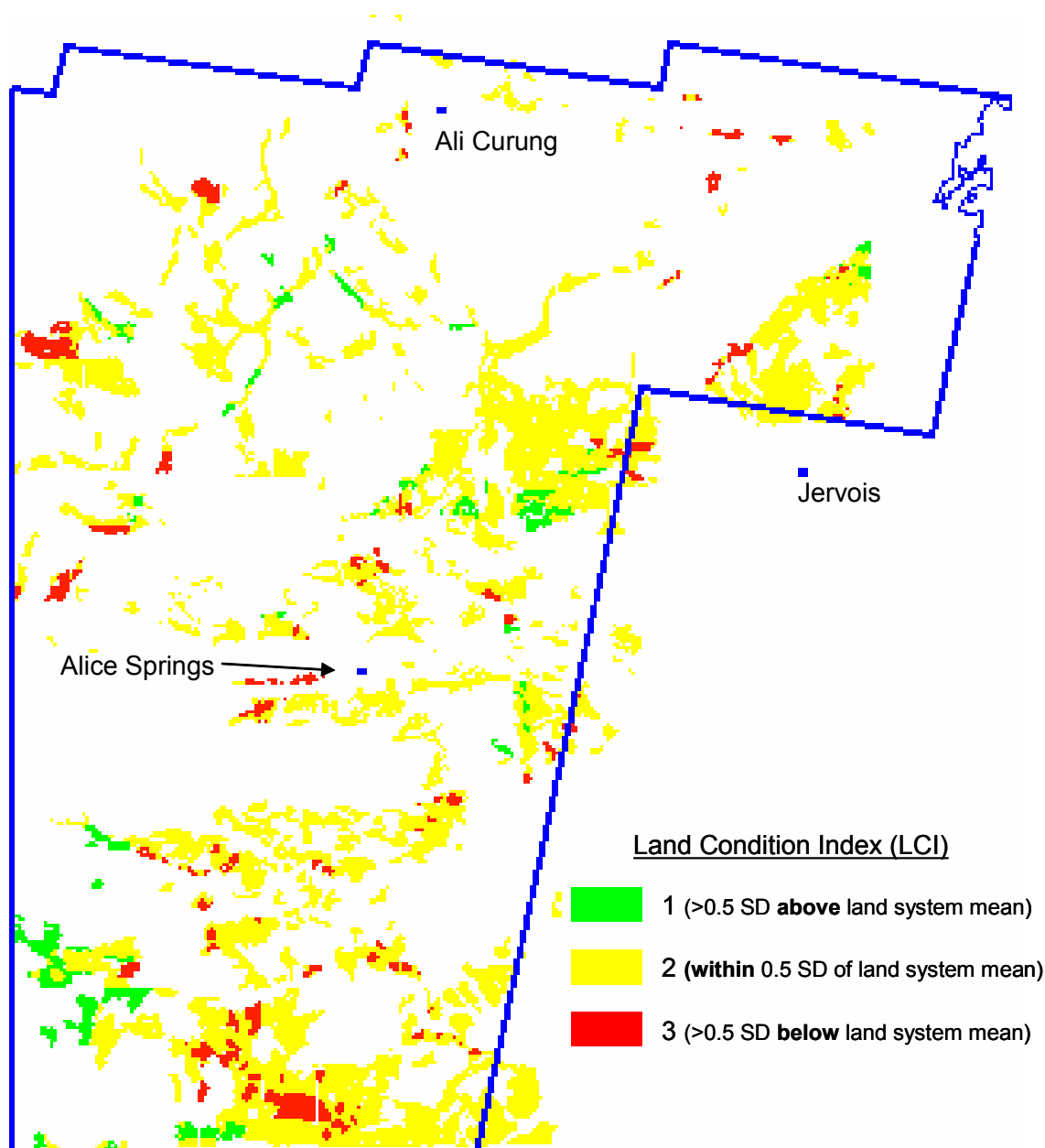


Figure A1.11: Mapped land condition index values for the 1999 image for land systems where cover tends to decrease with inappropriate grazing management

Notes: The blue polygon encloses the area of Landsat imagery common to all dates (i.e. area over which cover analyses conducted). The bottom of the image corresponds with the NT/SA border.

Alice Springs, Jervois and Ali Curung are shown for reference – these are the locations of meteorological stations with dust records.

The spatial location and extent of those land systems in paddocks where cover in 1999 was above (by $\frac{1}{2}$ SD) or below (by $\frac{1}{2}$ SD) the regional average for each land system is similar to that shown in Figure A1.10 (predominant result). It is difficult to see how areas coloured red are sufficiently extensive to be a significant source of dust.

Cover likely to increase due to woody thickening

Cohorts of trees and shrubs tend to germinate and establish successfully in wetter periods (e.g. 1950s, mid 1970s). Lack of fire and probable reduced competition from grasses through grazing are presumed to be the principal causes of woody thickening. Land systems that typically show such thickening are listed in Table A1.11.

Table A1.11: Land systems that tend to show an increase in cover with lack of fire and excessive or inappropriate grazing pressure

Pasture land	Land systems
Alternating hills and lowlands	Gillen, Hann, Hogarth, Ilbumric, Napperby, Stokes
Mulga	Boen, Bushy Park, Karee, Tietkins
Mulga mixed with spinifex sandplain	Alinga, Leahy
Spinifex	Amulda, Ewaninga, Middleton

Cover levels with distance from water

The percentage (of the total number) of land system–paddock combinations that had average cover **above**, **within** or **below** one-half standard deviation of the overall mean for the relevant land system at each image date is summarised in Table A1.12. The actual numbers are graphed in Figure A1.12 to assist visual interpretation. (Note that analysis is restricted to land systems with > 20 km² area in paddocks > 50 km² area.)

Although the group represents land systems that tend to show woody thickening (including increase in cover), this does not mean that cover has increased everywhere. Mean cover across the whole of Bushy Park land system in 2000 was similar to that present in 1972 (Figure A1.8). Average cover was higher in other years but there was no pattern of consistent increase over time. Rather, cover is likely to increase in some areas through woody thickening and this is likely to be offset by grazing effects (removal of herbage cover), particularly in dry years. Any areas that were burnt following the wet years of the mid 1970s will also contribute to lower average cover.

There was a consistently higher percentage of land system–paddock combinations in the ‘above’ category (i.e. mean cover greater than one-half standard deviation above the ‘global’ average for the land system) beyond 3 km from water compared with the area within 3 km from water (Table A1.11). This difference was greatest in earlier years (1972–1985, ~8%) and diminished between 1988 and 1992 (~2%) before again increasing at the end of the period (~7%). Conversely, there was a higher proportion of paddocks in the ‘below’ category closer to water compared with further from water. This difference was always >4%.

Table A1.12: For land systems where cover tends to increase through causes related to lack of fire and grazing, the percentage of land system–paddock combinations, and total count, where mean cover was above, within or below one-half standard deviation of the relevant mean land system cover at each image date

Distance from water	Cover category	Image date										
		1972	1980	1985	1988	1989	1991	1992	1995	1998	2000	2002
≤3 km	Above	14.2	14.2	6.2	12.4	11.5	10.6	10.6	8.0	4.4	8.0	10.7
	Within	55.8	60.2	67.3	67.3	71.7	69.0	63.7	74.3	70.8	72.6	71.4
	Below	30.1	25.7	26.5	20.4	16.8	20.4	25.7	17.7	24.8	19.5	17.9
	Total	113.0	113.0	113.0	113.0	113.0	113.0	113.0	113.0	113.0	113.0	112.0
>3 km	Above	24.3	21.6	14.5	15.5	12.3	12.7	12.3	12.7	10.5	15.5	17.7
	Within	52.3	67.0	70.0	71.8	76.4	71.4	71.8	73.6	76.4	70.0	70.9
	Below	23.4	11.5	15.5	12.7	11.4	15.9	15.9	13.6	13.2	14.5	11.4
	Total	218.0	218.0	220.0	220.0	220.0	220.0	220.0	220.0	220.0	220.0	220.0

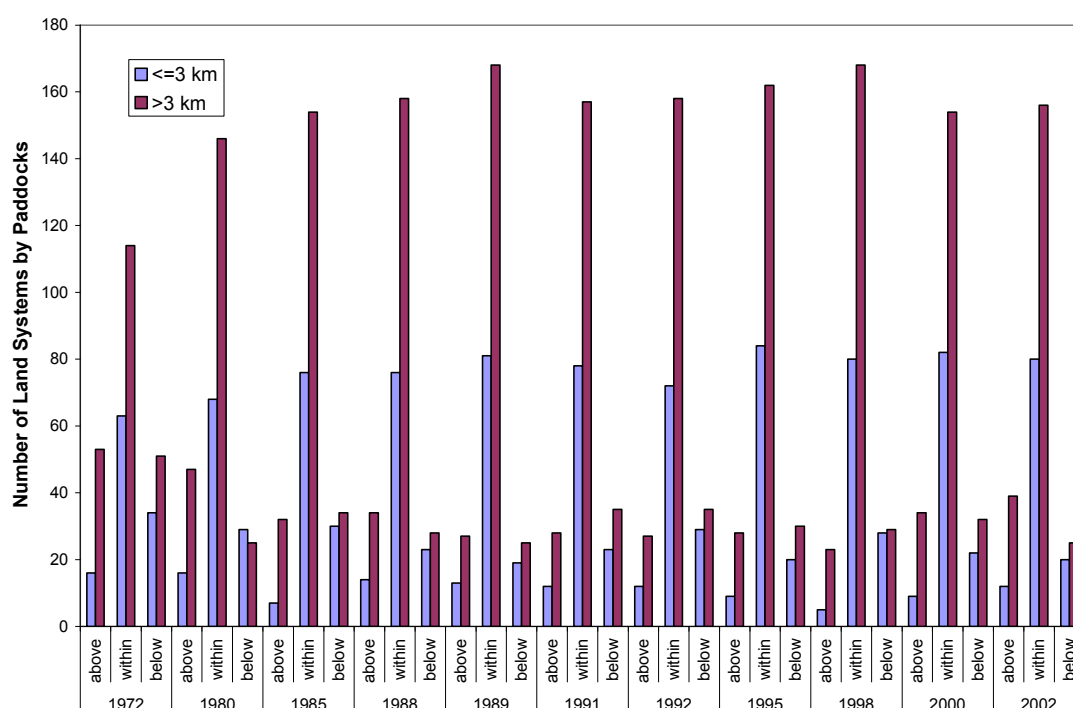


Figure A1.12: For land systems where cover tends to increase through causes related to lack of fire and grazing, the number of land system–paddock combinations where mean cover was above, within or below one-half standard deviation of the relevant mean land system cover at each image date

The consistency of cover categories for individual land system–paddock combinations through time is summarised in Table A1.13. Closer to water (0–3 km), a small number of land systems in paddocks had average cover consistently in the ‘below’ category (i.e. more than one-half standard deviation below the relevant land system ‘global’ mean). The number of paddocks was similar to that for the ‘beyond 3 km’ distance class. Slightly more land system–paddock combinations scored in the ‘above’ cover category further from water compared with closer to water.

Table A1.13: For land systems where cover tends to increase through causes related to lack of fire and grazing, the number of land system–paddock combinations showing a consistent (or near-constant) pattern of cover category through time

Cover category	Number of occurrences (based on image dates)	Number of land system–paddock combinations	
		≤3 km from water	>3 km from water
Below	11 (out of 11)	2	2
	10 (out of 11)	1	3
	9 (out of 11)	5	3
Above	11 (out of 11)	0	0
	10 (out of 11)	1	2
	9 (out of 11)	2	3

Note: Cover categories are above, within or below one-half standard deviation of the relevant mean land system cover at each image date.

The majority of land system–paddock combinations for both distance-from-water classes had a shifting pattern of cover category through time, with most fluctuating between either the ‘below’ and ‘within’ categories (i.e. generally lower cover) or ‘within’ and ‘above’ categories (generally higher cover) – supported by the data in Table A1.14.

Table A1.14: For land systems where cover tends to increase through causes related to lack of fire and grazing, the number of land system–paddock combinations showing either no change or substantial change in cover categories based on cover present in the 1972 and 2000 image dates

Distance from water category	Cover category combinations ¹ – number of land system–paddock combinations			
	Below – Below i.e. no change	Below – Above substantial change	Above – Below substantial change	Above – Above i.e. no change
≤3 km	0	4	1	9
>3 km	7	7	6	13

¹Based on cover category for each land system–paddock combination in the 1972 and 2000 image dates.

Although focusing on change in cover category between particular years only conveys part of the overall pattern of change, it is another way of condensing results. The major changes in status of land system–paddock combinations between the image dates of 1972 and 2000 (actually, 1999) is summarised in Table A1.14. (As for those land systems where cover tends to decrease with excessive grazing, I have used the 2000 image date for this ‘woody increase’ group as well – in preference to 2002. This is because the 2000 image better relates to the probable dry seasonal conditions prevailing at the time of acquiring the 1972 imagery.)

Land systems and stations

Table A1.5 summarises paddock by land system combinations of predominant cover category through time for land systems that tend to show cover increase over time through causes related to lack of fire and grazing. As for land systems above where cover tends to decrease with heavy grazing, cover was considered ‘predominantly above’ if more than half of the 11 image dates had a mean cover for the land system–paddock combination greater than one-half of a standard deviation above the global mean for that land system. Similarly, cover was ‘predominantly below’ if more than half of the 11 image dates had a mean cover for the land system–paddock combination greater than one-half of a standard deviation below the global mean for that land system.

Closer to water (≤3 km) summed over all stations, three times as many paddock – land system combinations showed predominantly lower levels of mean cover between 1972 and 2002 compared with predominantly higher cover. This suggests that grazing effects in paddocks showing the most marked deviations from overall mean cover of each land system were quite strong and were acting to reduce cover more so than any cover increase caused by localised woody thickening. Further from water (>3

km), there was an approximately equal number of paddock – land system combinations (summed across all stations) with cover either predominantly above or below the global mean of each land system in this ‘woody increase’ group.

The red-earth plains on ancient alluviums with mulga, mapped as Bushy Park land system, are the most extensive (in area) in this grouping (land system areas in Appendix 2b). Its extensive area is probably the main reason why Bushy Park land system had the greatest number of paddocks showing predominantly above or below average cover through time (Table A1.16). At both distance-from-water classes, there were more paddocks with predominantly below average cover than above. For the other dominant land systems (Boen: mulga on red earth; and Gillen: sandstone ranges with mulga and witchetty bush), there were more paddocks with below-average cover (compared with above average) closer to water with the reverse situation (just) applying further from water.

Table A1.15: For land systems where cover tends to increase through causes related to lack of fire and grazing, the number of paddock by land system combinations on each station where mean cover was predominantly above or below the overall mean for that land system through time

Station	Distance from water ≤3 km		Distance from water >3 km		Total land system by paddock combinations
	Predominant paddock by land system cover category				
	Above	Below	Above	Below	
Aileron	1		2		3
Alcoota		1			1
Allambi		1			1
Amburla	1	1			2
Angas Downs			3		3
Anningie			1	2	3
Annitowa				1	1
Bond Springs	1				1
Deep Well			1		1
Derry Downs		1		1	2
Elkedra		1		1	2
Glen Helen	1		1	1	3
Hamilton Downs	1		2		3
Horseshoe Bend		1			1
Idracowra		1	1		2
Lilla Ck				1	1
Loves Ck		1	1		2
MacDonald Downs		1		2	3
Maryvale		1		1	2
Mt Cavenagh			1		1
Napperby		1		3	4
Narwietooma		1		1	2
Neutral Junction		2	1	1	4
Old MacDonald Dns				2	2
Owen Springs			1		1
Pine Hill	1		1		2
Stirling			1		1
Umbeara		1		1	2
Undoolya		1			1
Victory Downs			2		2
Woodgreen		2		1	3
Yalrirakinu ALT		1			1
Yambah			3		3
Total	6	19	22	19	66

Table A1.16: For land systems where cover tends to increase through causes related to lack of fire and grazing, the number of paddocks where mean cover was predominantly above or below the overall mean for that land system through time

Land system	Distance from water ≤3 km		Distance from water >3 km		Total number of paddocks
	Predominant cover category for paddocks through time				
	Above	Below	Above	Below	
Alinga		1		1	2
Amulda		1	2		3
Boen	2	3	3	2	10
Bushy Park	3	6	7	10	26
Gillen	1	4	4	1	10
Hann		1		1	2
Ilbumric			1	2	3
Karee		1	3	2	6
Middleton		1	1		2
Napperby		1			1
Stokes			1		1
Total	6	19	22	19	66

Mapped land condition classes – cover increase due to woody thickening

Land systems (>20 km²) in paddocks (>50 km²) showing a predominant pattern of cover above, below or within one half standard deviation of the global mean for each land system throughout the reporting period are mapped in Figure A1.13. This mapping is for those land systems that tend to show cover increase due to fire suppression, and, possibly, inappropriate grazing management (Table A1.11). ‘Predominant’ is defined as the dominant result from more than half of the available 11 image dates.

Areas with predominantly below or above average cover are relatively small and widely separated – a similar result to that presented for those land systems where cover tends to decrease with inappropriate grazing (Figure A1.10).

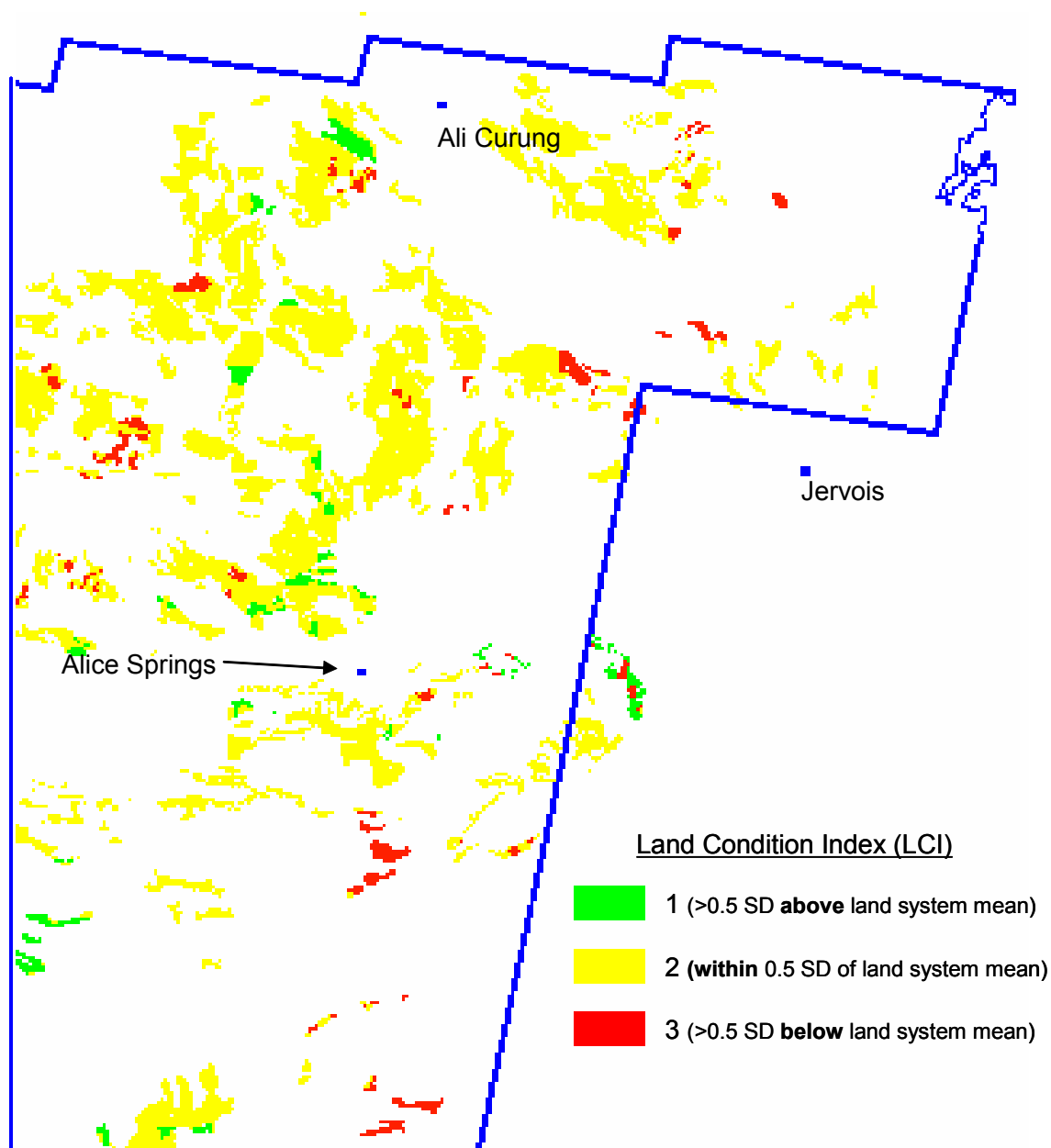


Figure A1.13: Mapped land condition index values for land systems where cover tends to increase due to fire suppression, and, possibly, inappropriate grazing management

Notes: The blue polygon encloses the area of Landsat imagery common to all dates (i.e. area over which cover analyses conducted). The bottom of the image corresponds with the NT/SA border.

Alice Springs, Jervois and Ali Curung are shown for reference – these are the locations of meteorological stations with dust records.

'Predominant' is the dominant result from more than half of the available 11 image dates.

Cover change affected by wildfire

This group includes the spinifex-dominant 'desert' land systems Simpson, Singleton, Tennant Creek and Wonorah.

Cover levels with distance from water

The percentage (of the total number) of land system–paddock combinations that had average cover *above*, *within* or *below* one-half standard deviation of the overall mean for the relevant land system at each image date is summarised in Table A1.17. The actual numbers are graphed in Figure A1.14 to assist visual interpretation.

Compared with the two previous land system groupings, this group had:

- A smaller difference between the percentage of land system–paddock combinations in the higher ('above') and lower ('below') cover categories (Table A1.17). Periodic (or in some cases, episodic) fire and the spatially distributed variable stages of post-fire regeneration probably had a moderating effect on the range of cover levels.
- A smaller difference in percentage of land system–paddock combinations across the two distance-from-water classes. This probably results from the combined effects of recent fire to reduce cover wherever it had occurred and, minimal grazing impact to lower average cover levels closer to water (i.e. the ≤ 3 km distance class).

Table A1.17: For land systems where cover is affected by wildfire, the percentage of land system–paddock combinations, and total count, where mean cover was above, within or below one-half standard deviation of the relevant mean land system cover at each image date

Distance from water	Cover category	Image date										
		1972	1980	1985	1988	1989	1991	1992	1995	1998	2000	2002
≤ 3 km	Above	22.1	26.0	29.2	17.0	19.8	21.7	21.7	19.8	20.7	19.8	35.8
	Within	59.6	56.7	48.1	61.3	54.7	56.6	56.6	60.4	51.9	52.8	56.6
	Below	18.3	17.3	22.6	21.7	25.5	21.7	21.7	19.8	27.4	27.4	7.5
	Total	104.0	104.0	106.0	106.0	106.0	106.0	106.0	106.0	106.0	106.0	106.0
>3 km	Above	23.2	32.3	27.2	21.9	21.3	24.3	17.8	25.4	22.5	22.5	39.6
	Within	62.2	53.7	56.2	63.3	60.4	56.2	66.9	60.4	62.1	62.7	50.9
	Below	14.6	14.0	16.6	14.8	18.3	19.5	15.4	14.2	15.4	14.8	9.5
	Total	164.0	164.0	169.0	169.0	169.0	169.0	169.0	169.0	169.0	169.0	169.0

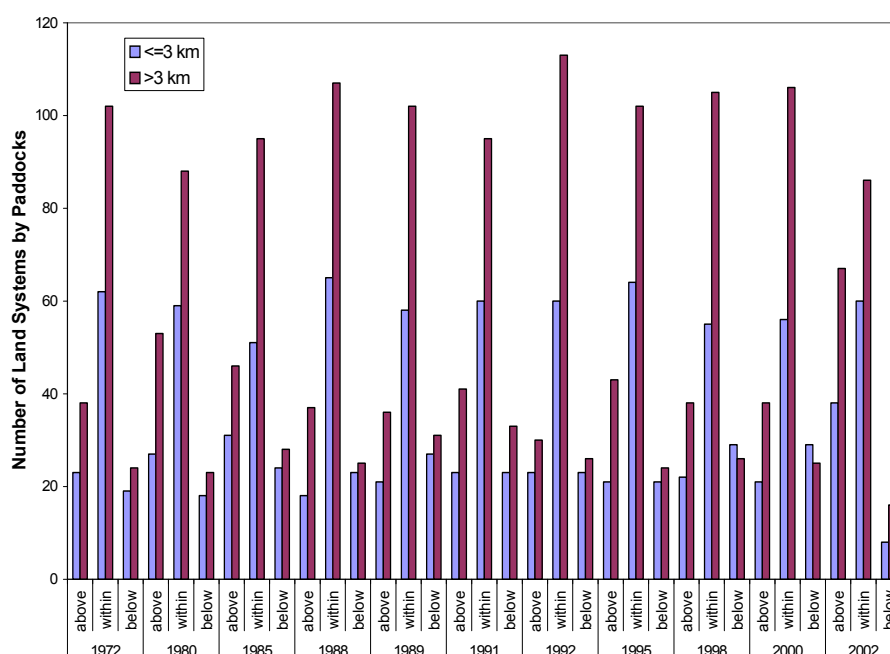


Figure A1.14: For land systems where cover is affected by wildfire, the number of land system–paddock combinations where mean cover was above, within or below one-half standard deviation of the relevant mean land system cover at each image date

The consistency of cover categories for individual land system–paddock combinations through time is summarised in Table A1.18. At both distance-from-water classes, only one land systems – paddock combination had average cover consistently in the ‘below’ category (i.e. more than one-half standard deviation below the relevant land system ‘global’ mean). Conversely, six land system–paddock combinations had consistently higher cover closer to water (≤ 3 km) at all image dates and 10 further from water. The higher number of ‘consistently above’ land system–paddock combinations, compared with ‘consistently below’, may have been related to active fire suppression by management. However, land system differences seem more likely. Three paddocks on Lyndavale (at both distance classes) and three paddocks on Victory Downs (closer to water, four paddocks beyond 3 km) contain Simpson land system. This mapped area of Simpson land system has sand dunes, but is vegetated with moderately dense mulga in the swales, and with other shrubs on the sand hills rather than with the more usual spinifex. Fire has generally been excluded, and several of the waters on Lyndavale are recent (established during the 1990s). Thus, it is more likely that the persistent cover of mulga and other shrubs produce the consistently higher cover in the first ‘above’ row of Table A1.18.

Table A1.18: For land systems where cover is affected by wildfire, the number of land system–paddock combinations showing a consistent (or near-constant) pattern of cover category through time

Cover category	Number of occurrences (based on image dates)	Number of land system–paddock combinations	
		≤ 3 km from water	>3 km from water
Below	11 (out of 11)	1	1
	10 (out of 11)	4	3
	9 (out of 11)	6	6
Above	11 (out of 11)	6	10
	10 (out of 11)	3	1
	9 (out of 11)	2	1

No land system–paddock combinations showed marked shifts in mean cover between the two reporting periods 1972 and 2000 (Table A1.19). This was a different result from that for the two previously reported land-system groupings where several land systems in paddocks fluctuated between the two extremes. A higher number of land system–paddock combinations had the same cover category at both times (i.e. below average or above average at both occasions) compared with the two previous groupings. Remaining paddock – land system combinations oscillated between less extreme cover categories between 1972 and 2000.

Table A1.19: For land systems where cover is affected by wildfire, the number of land system–paddock combinations showing either no change or substantial change in cover categories based on cover present in the 1972 and 2000 image dates

Distance from water category	Cover category combinations ¹ – number of land system–paddock combinations			
	Below – Below i.e. no change	Below – Above substantial change	Above – Below substantial change	Above – Above i.e. no change
≤ 3 km	14	0	0	15
>3 km	11	0	0	23

¹Based on cover category for each land system–paddock combination in the 1972 and 2000 image dates.

Land systems and stations

Table A1.20 summarises Paddock by land system combinations of predominant cover category through time for land systems where cover is affected by wildfire. As for land systems in the two previous groupings, cover was considered ‘predominantly above’ if more than half of the 11 image dates had a mean cover for the land system–paddock combination greater than one-half of a standard deviation above the global mean for that land system. Similarly, cover was ‘predominantly below’ if more than half of the 11 image dates had a mean cover for the land system–paddock combination greater than one-half of a standard deviation below the global mean for that land system.

Closer to water (≤ 3 km), an equal number of paddock–land system combinations, summed across all stations, showed predominantly lower and higher levels of mean cover between 1972 and 2002. Further from water, almost twice as many paddock–land system combinations had predominantly higher cover compared with predominantly lower cover (36 compared with 21). Similarly, there were almost twice as many paddock–land system combinations with higher cover further from water compared with closer to water (36 compared with 19). These two results suggest a marked grazing effect in some paddocks, but I discount this in favour of the distinct regional differences described above for the very extensive Simpson land system (i.e. paddocks on Lyndavale and Victory Downs where moderately dense mulga occurs in swales with other shrubs on sand hills – rather than the more usual spinifex).

There were several paddocks with Simpson or Singleton land systems where cover was predominantly above or below the average response for each land system through the reporting period (Table A1.21). Again, these results suggest grazing effects, but I discount this due to the extensive occurrence of both land systems and likely differences among paddocks resulting from recent fire history, and, possibly, rainfall.

Mapped land condition classes – cover change affected by wildfire

Figure A1.15 maps Land systems (>20 km²) in paddocks (>50 km²) showing a predominant pattern of cover above, below or within one half standard deviation of the global mean for each land system throughout the reporting period. This mapping is for those ‘desert’ land systems where cover is more affected by wildfire than grazing (Simpson, Singleton, Tennant Creek and Wonorah land systems). ‘Predominant’ is defined as the dominant result from more than half of the available 11 image dates.

Table A1.20: For land systems where cover is affected by fire, the number of paddock by land system combinations on each station where mean cover was predominantly above or below the overall mean for that land system through time

Station	Distance from water ≤3 km		Distance from water >3 km		Total land system by paddock combinations
	Predominant paddock by land system cover category				
	Above	Below	Above	Below	
Aileron	1		2		3
Allambi		2			2
Amburla			1		1
Ammaroo	1		2		3
Anningie	2		2		4
Annitowa		2		4	6
Arapunya		1		2	3
Bushy Park			2		2
Coniston			1		1
Derry Downs		2		2	4
Derwent	2		3		5
Elkedra		1		1	2
Erlunda			1		1
Henbury		1			1
Horseshoe Bend		3		3	6
Idracowra		2	1	1	4
Lilla Creek		2			2
Lucy Creek		2		2	4
Lyndavale	3		4		7
Maryvale		1		1	2
Mt Denison			1		1
Mt Skinner			1		1
Murray Downs	1				1
Neutral Junction			1		1
New Crown				2	2
Owen Springs	1		1		2
Pine Hill	1		2		3
Stirling	3		4		7
Todd River				2	2
Umbeara	1		1		2
Undoolya				1	1
Victory Downs	3		4		7
Yambah			2		2
Total	19	19	36	21	95

Table A1.21: For land systems where cover is affected by fire, the number of paddocks where mean cover was predominantly above or below the overall mean for that land system through time

Land system	Distance from water ≤3 km		Distance from water >3 km		Total number of paddocks
	Predominant cover category for paddocks through time				
	Above	Below	Above	Below	
Simpson	10	9	12	7	38
Singleton	9	10	24	13	56
Wonorah				1	1
Total	19	19	36	21	95

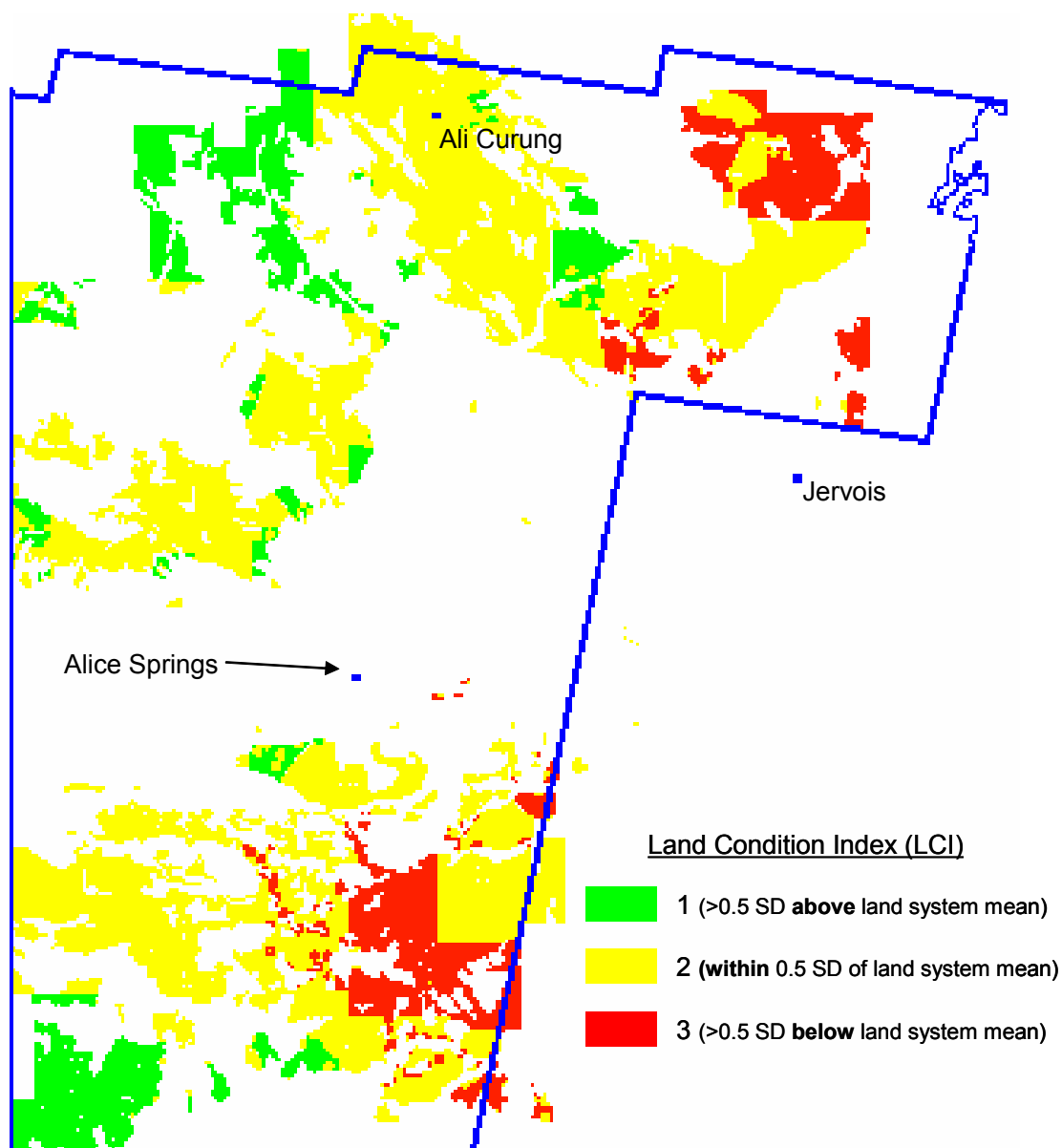


Figure A1.15: Mapped land condition index values for land systems where cover is affected by wildfire

Notes: The blue polygon encloses the area of Landsat imagery common to all dates (i.e. area over which cover analyses conducted). The bottom of the image corresponds with the NT/SA border.

Alice Springs, Jervois and Ali Curung are shown for reference – these are the locations of meteorological stations with dust records.

'Predominant' is the dominant result from more than half of the available 11 image dates.

Areas of land systems within paddocks where cover was affected by wildfire with predominant cover above or below the regional land system average are more extensive and grouped than for the two previous land types (compared with Figs. 10 and 13). This is likely due to the greater regional extent of these ‘desert’ land systems (particularly Simpson and Singleton) and the large size of ‘paddocks’ in these desert areas. It may be that the regional occurrence of extensive areas of below-average cover following fire, particularly in dry years, contributes to atmospheric dust levels recorded at Alice Springs (and perhaps at other meteorological stations).

4. Concluding remarks

The purpose of this work was to:

- Examine seasonal variation in vegetation cover for a substantial area of the Alice Springs pastoral district in the southern NT. Cover was derived from Landsat imagery for 11 image dates between 1972 and 2002.
- Test whether there were any obvious grazing effects on cover levels by comparing mean cover for each land system within 3 km of water with that beyond 3 km.
- Develop and test an indicator of land condition that may have application for reporting pastoral land management as part of an environmental management system (EMS).
- By grouping land systems into cover-response categories related to grazing and/or fire, qualitatively test whether the land condition indicator (LCI) has any relationship with risk of dust generation.

Environmental management systems have been proposed as a vehicle for certifying (or at least crediting) meat and fibre products from the rangelands as being produced in an environmentally benign (‘green’) way. Although not yet established in practice, it is argued that such labelling, supported by suitable monitoring and documentation, may enhance access to markets (or in the future, maintain it as consumers become more discerning in their purchasing choices).

It would seem reasonable that maintenance of minimum acceptable levels of various forms of vegetation cover could feasibly be a component of a credible EMS. Cover (including type) is relatively easy to specify and feasible to monitor, particularly with remote sensing (although it is difficult to distinguish and monitor different cover types in remotely sensed data). The expanding archive of satellite imagery and the declining cost of some data sources (including MODIS, which is free) increase the attractiveness of remote sensing.

Cover is also sensible as a component of an EMS because minimum levels are critical for maintaining landscape function, that is, the ability of landscapes to capture and retain rain water and nutrients – the vital, but scarce, resources for plant growth in most rangelands. While loss of water through increased runoff and associated erosion is the most obvious form of resource leakage, loss of nutrients in dust may also be a significant cause of decline in landscape function in some land types. Despite the recognised importance of cover for both landscape function and sustained pastoral production, benchmark threshold levels of various cover types have not yet been specified for most land types.

Operationally, any EMS for the pastoral industry must be sufficiently comprehensive and convincing to meet market requirements, but technically, no more complex to operate than need be. This work has explored one approach to analysing and reporting paddock and land-type cover levels through time. This work demonstrates that large datasets can be efficiently analysed and reported although much still has to be done to communicate (and debate) the approach taken, refine methods, and validate results, as the possible first steps in incorporating analysis of remotely-sensed cover into an EMS. These analyses are

still beyond the scope of individual producers to undertake but they might feasibly be undertaken by an industry body or suitable agent on behalf of landholders in an EMS group – once suitable analysis pathways are specified.

One notable weak link in my current reporting is the land condition index. Robust and meaningful condition indices are difficult to establish. The purpose here was to devise an index (or at least, indicator) that differentiates management effects on cover (here, inappropriate or excessive grazing as the main contributor to increased risk of dust generation) from those due to season (rainfall), natural landscape variability and wildfire. If the proposed index has any potential, it needs much further intellectual development and testing before it can be considered a component of an EMS. Foremost among its present limitations is the seemingly minimal (non-existent?) connection between reported condition scores of land systems (within their groupings, Tables A1.5 and A1.11) and risk of dust generation.

Other areas needing attention to improve analysis and quality of reported results include:

- Landscape stratification. Land systems are convenient, but at their mapped 1:1 000 000 scale are regional in nature, and some (many?) are probably too heterogeneous to provide a suitable basis for the required form of stratification. Unfortunately though, nothing else is available or suitable at the scale of regional analysis.

Land systems also vary in their regional extent. Some are quite ‘local’ in that they map often narrow or elongated alluvial features or distinct soil types with corresponding vegetation associations. Others are extensive and occur across much of the analysis region – particularly spinifex sandplain, sand dunes and mulga shrublands. Mean levels of cover calculated for the more extensive land systems may well reflect seasonal variations in rainfall, with this effect dominating any effects of land (grazing) management that the land condition indicator seeks to identify.

- The grouping of land systems into ‘vegetation-response’ types may also be flawed and needs further consideration. I used the three groupings (cover likely to decrease with inappropriate grazing, cover likely to increase through woody thickening (fire suppression and perhaps inappropriate grazing practices) and cover likely to vary with wildfire (the ‘desert’ land systems)) to both constrain and direct analysis. It may well be that this coarse grouping is too general and generates additional unacceptable heterogeneity. However, in implementing a regional EMS, there is a need for a simple but robust approach to rapid and systematic analysis of large remotely sensed datasets.
- The variable size of paddocks. I used major land systems within larger paddocks as the analysis unit, but paddock size is quite variable – there are many smaller paddocks in the analysis region and a considerable number of very large ‘paddocks’ (almost the entire area of some minimally developed stations). This size variation, combined with the variable area and extent of land systems (above) provides an unequal-area basis for analysis and may distort the comparison/interpretation and mapped display of results.

In conclusion, the cover analysis results and possible land condition index presented here are exploratory. The approach allows rapid and relatively easy identification of those areas where cover is above or below the (regional) land system average at each image date, and the extent to which these differences predominate through time (30-year period). The land condition index as presented is tenuous. It may have some potential for improvement as a cover-based component of an EMS for the pastoral industry. However, from the perspective of risk of dust generation, those areas mapped LCI 3 (below-average) probably have little relationship with actual areas of dust generation.

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Appendix 1a: PD54 Parameters

Table A1.22: Parameters used to calculate PD54 cover index values for each image date

Map Sheet	Quadrant used	Date	Actual Values			Values to Use		
			Gain	Offset	Distance	Gain	Offset	Distance
SF53	south west	2002	0.68	80.50	66.88	0.68	80.50	66.0
SG53	north west	2002	0.68	80.50	70.72			
SF53	south west	2000	0.68	76.06	66.41	0.68	68.50	59.0
SG53	north west	2000	0.68	68.50	57.97			
SF53	south west	1998	0.68	80.50	70.36	0.68	80.50	70.0
SG53	north west	1998	0.68	80.50	72.61			
SF53	south west	1995	0.68	76.06	69.71	0.68	76.06	65.5
SG53	north west	1995	0.68	76.06	65.89			
SF53	south west	1992	0.68	76.06	64.19	0.68	68.50	59.0
SG53	north west	1992	0.68	71.31	59.71			
SF53	south west	1991	0.68	76.06	64.19	0.68	76.06	65.5
SG53	north west	1991	0.68	80.50	66.04			
SF53	south west	1989	0.68	76.06	71.23	0.68	80.50	70.0
SG53	north west	1989	0.68	80.50	69.03			
SF53	south west	1988	0.68	68.50	59.31	0.68	68.50	59.0
SG53	north west	1988	0.68	68.50	59.16			
SF53	south west	1985	0.68	76.06	66.34	0.68	76.06	65.5
SG53	north west	1985	0.68	80.50	68.23			
SF53	south west	1980	0.68	87.71	81.62	0.68	80.50	66.0
SG53	north west	1980	0.68	80.50	64.84			
SF53	south west	1972	0.68	76.06	68.44	0.68	76.06	69.5
SG53	north west	1972	0.68	80.50	72.19			

Appendix 1b: Land system descriptions and areas

Table A1.23: Areas and descriptions of land systems, grouped by pasture land.

Pasture land	Land system	Description	Area (km ²)	% of area
Mountains and hills	Cherry Creek	Low plateaux of shale and limestone	1721	0.9
	Davenport	Bevelled sandstone ridges	3239	1.7
	Harts	Gneiss and granite mountains	9918	5.1
	Huckitta	Limestone mountains	779	0.4
	Krichauff	Sandstone plateaux	5610	2.9
	Pertnara	Conglomerate hills and ridges	719	0.4
	Reynolds	Gravel terraces and rocky rises	229	0.1
	Santa Teresa	Plateaux of chalcedony	119	0.1
	Sonder	Sandstone mountains with mulga or witchetty bush country	3860	2.0
	Tomahawk	Low sandstone plateaux	122	0.1
Area – mountains and hills (km²)			26316	13.6
Alternating Hills and Lowlands	Aileron	Granite mountains with mulga country and spinifex sandy plains	281	0.1
	Allua	Limestone mountains, valleys open or with gidgee	1470	0.8
	Bond Springs	Hills of metamorphic rocks, and sparse low tree country	2161	1.1
	Cavenagh	Granite hills and witchetty bush country	605	0.3
	Chisholm	Low rugged rises of metamorphic rocks; open plains with short grass-forb pastures, mulga country	680	0.4
	Coghlan	Low shale hills, sparse low trees on lowlands	88	0.0
	Gillen	Sandstone mountains with mulga or witchetty bush country	4995	2.6
	Hann	Sandstone hills, and spinifex and sparse low tree country	1981	1.0
	Hogarth	Sandstone uplands over limestone, and gidgee country	690	0.4
	Ilbumric	Low hills and ridges of sandstone, greywacke and siltstone, and mulga country	1811	0.9
	Ilgulla	Limestone plateaux and gidgee	1047	0.5
	Kurundi	Hills of volcanic rocks, lowlands open or with gidgee	465	0.2
	Napperby	Granite and gneiss mountains and lowlands	1921	1.0
	Rumbulara	Duricrusted shale mesas, open lowlands with Sclerolaena spp	2289	1.2
	Stokes	Stony terraces, and mulga or sparse low tree country	1310	0.7
	Table Hill	Low chalcedony mesas and plateaux, valleys open with short grass-forb pastures	565	0.3
	Weldon	Low rocky terraces and sparse low tree country	361	0.2
Area – alternating hills and lowlands (km²)			22721	11.7
Sparse Low Tree Country	Alcoota	Plains on weathered gneiss etc, short grass-forb pastures under sparse low trees, mulga, or treeless	2407	1.2
	Anderinda	Plains on granite, schist and gneiss, mainly short grass-forb pastures under sparse low trees	389	0.2
	Barrow	Plains on granite, mainly short grass-forb pastures, treeless or with sparse low trees	264	0.1
	Ennugan	Plains on weathered schist and gneiss with short grass-forb pastures under sparse low trees or mulga	566	0.3
	Indiana	Plains on schist and gneiss, short grass-forb pastures under sparse low trees or treeless, some spinifex	99	0.1
	Ryan	Plains on weathered granite and gneiss with short grass-forb pastures under sparse low trees or treeless	689	0.4
	Warburton	Plains on weathered granite, schist and gneiss, short grass-forb or woollybutt pastures under low trees	1266	0.7
Area – sparse low tree country (km²)			5681	2.9
Mulga	Boen	Plains mainly short grass-forb or woollybutt pastures under mulga, minor depressions with denser mulga	6423	3.3
	Bushy Park	Alluvial plains, mainly red earths with short grass-forb or woollybutt pastures under mulga	13128	6.8
	Karee	Alluvial plains with sandy soil carrying mainly woollybutt or short grass-forb pastures under mulga	1230	0.6
	Tietkins	Granite plains with sandy soil carrying mainly woollybutt or short grass-forb pastures under mulga	357	0.2
Area – mulga (km²)			21138	10.9

Pasture land	Land system	Description	Area (km ²)	% of area
Mulga mixed with Spinifex sand plain	Alinga	Plains on sandstone, shale, and thin limestone, mainly short grass-forb under mulga, some soft spinifex	1975	1.0
	Leahy	Alluvial plains, mainly short grass-forb or woollybutt pastures under mulga, smaller areas with spinifex	302	0.2
	Lindavale	Limestone plains with short grass-forb or woollybutt pastures under mulga, some hard spinifex	2402	1.2
Area – mulga mixed with Spinifex sand plain (km²)			4679	2.4
Witchetty bush	Muller	Conglomerate plains with short grass-forb pastures under witchetty bush or open, some spinifex	1106	0.6
	Outounya	Granite and schist plains with short grass-forb pastures under witchetty bush	1560	0.8
Area – witchetty bush (km²)			2666	1.4
Gidgee	Delny	Plains, mostly covered by laterite or limestone, short grass-forb pastures under witchetty bush	1195	0.6
	Lucy	Limestone plains, mainly short grass-forb pastures under gidgee or witchetty bush, some treeless	2219	1.1
	Ooratippra	Limestone plains, short grass-forb pastures mainly under gidgee, some under mulga	535	0.3
	Pulya	Broad valleys in MacDonnell Ranges, mainly short grass-forb pastures under gidgee or treeless	416	0.2
	Ringwood	Plains of calcareous alluvium, mainly short grass-forb pastures under gidgee or treeless	978	0.5
Area – gidgee (km²)			5342	2.8
Variable sparse low vegetation	Titra	Partly sand-covered limestone plains, complex pattern of vegetation, mainly short grass-forb pastures	726	0.4
	Woolla	Linear limestone plains, mainly short grass-forb pastures with sparse cover of shrubs and low trees	681	0.4
Area – variable sparse low vegetation (km²)			1407	0.7
Short grass – Young alluvia	Adnera	Alluvial fans with short grass-forbs or woollybutt under mulga, some treeless short grass-forb pastures	174	0.1
	Ammaroo	Terminal floodplains in north of area, mainly short grass-forbs with patches of better pastures	680	0.4
	Deering	Alluvial plains with Sclerolaena spp. pastures, open or with sparse shrubs	50	0.0
	Finke	Sandy floodplains in south of area, mainly short grass-forbs under sparse low trees	1023	0.5
	Hamilton	Alluvial plains, mostly short grass-forbs, treeless on clayey soils, under mulga on sandy soils	794	0.4
	Kanandra	Sandy alluvia north of Harts Range, with mainly kerosene grass under sparse low trees	2357	1.2
	McGrath	Floodplains with mainly red-earth soils carrying short grass-forbs under sparse low trees or mulga	788	0.4
	Sandover	Sandy floodplains in north of area, mainly short grass-forbs under sparse low trees	3488	1.8
	Todd	Sandy and loamy alluvia with mainly short grass-forbs under sparse low trees	681	0.4
	Utopia	Alluvial basins liable to flooding, heavy clay soils with northern bluebush pastures	48	0.0
	Woodduck	Sandy alluvial fans with short grass-forbs under sparse low trees, some sandy plains with hard spinifex	710	0.4
Area – short grass – young alluvia (km²)			10792	5.6
Bluebush country	Ebenezer	Undulating stony calcareous plains, mainly with southern bluebush	2350	1.2
	Lilla	Gently sloping terraces with southern bluebush, smaller areas of stony slopes carrying bladder saltbush	805	0.4
	Renners	Undulating shale and limestone country, mainly sparse southern bluebush	749	0.4
Area – bluebush country (km²)			3904	2.0
Saltbush country	Endinda	Plains with mainly bladder saltbush pastures, minor sand dunes with spinifex	199	0.1
	Kalamerta	Sandy plain, mainly bladder saltbush under mulga, some woollybutt or short grass-forb pastures under mulga	643	0.3
	Kulgera	Plains with bladder saltbush pastures, medium areas of plains with short-grass forb pastures	200	0.1
	Peebles	Stony undulating to low hilly country, mainly bladder saltbush or Sclerolaena spp. pastures	842	0.4

Pasture land	Land system	Description	Area (km ²)	% of area
Area – saltbush country (km²)			1885	1.0
Mitchell grass	Ambalindum	Calcareous terraces, sparse Mitchell grass pastures, minor bladder saltbush and southern bluebush, cottonbush	394	0.2
	Undippa	Plains on fine-textured alluvia, mainly barley Mitchell grass, minor northern bluebush pastures	367	0.2
Area – Mitchell grass (km²)			761	0.4
Open country with Sclerolaena pastures	Chandlers	Plains, some hills, mainly Sclerolaena spp. pastures, open or with sparse shrubs	2392	1.2
Area – open country with Sclerolaena pastures (km²)			2392	1.2
Spinifex	Amulda	Sandy plains with hard spinifex pastures, some floodplains with short grass-forb pastures	308	0.2
	Angas	Sandy plains with hard spinifex pastures, some southern bluebush pastures on stony, heavier soils	1123	0.6
	Ewaninga	Undulating sandy country and conglomerate rises with mainly hard spinifex pasture under mulga	1618	0.8
	Middleton	Sandy plains with hard spinifex pastures, some rocky hills	793	0.4
	Simpson	Extensive dune fields with hard spinifex pastures	28202	14.6
	Singleton	Extensive sandy plains with mainly hard spinifex, some feathertop and soft spinifex pastures	49069	25.3
	Tennant Creek	Plains and low hills, mainly soft spinifex pastures in north of area	97	0.0
	Wonorah	Plains with isolated low hills, mainly soft spinifex pastures in north of area	784	0.4
Area – Spinifex (km²)			81994	42.4
Salt lake	Amadeus	Salt pans and dune fields	1929	1.0
Total area of all pasture lands and land systems (km²)			193604	100.0

Appendix 1c: Mean cover of land systems for each image date

Table A1.24: Mean cover of each land systems for each image date.

Pasture land	Land system	Year (Epoch)										
		1972	1980	1985	1988	1989	1991	1992	1995	1998	2000	2002
Mountains and Hills	Cherry Creek	34.2	57.1	43.2	49.4	51.9	48.4	51.0	47.7	49.8	39.7	64.5
	Davenport	49.1	61.8	57.2	47.8	55.3	50.9	45.6	53.5	59.3	47.9	63.0
	Harts	47.2	64.9	57.8	49.2	58.9	54.7	48.1	56.6	58.7	54.6	72.0
	Huckitta	46.7	60.2	57.4	49.8	59.9	54.6	47.2	51.6	51.9	50.3	68.7
	Krichauff	45.4	59.2	50.5	47.1	54.7	53.1	49.7	54.0	55.8	46.5	66.2
	Pertnjara	54.9	70.3	67.0	56.5	62.4	60.5	48.6	57.1	57.7	53.5	73.9
	Reynolds	36.4	54.2	51.9	39.3	55.0	47.7	38.8	46.2	53.1	46.6	65.5
	Santa Teresa	27.6	67.1	54.5	38.0	51.5	44.6	29.6	40.4	39.0	35.5	65.8
	Sonder	50.4	67.6	57.6	53.4	59.7	56.1	50.8	57.6	58.2	52.7	73.0
	Tomahawk	51.1	55.1	56.2	47.6	56.5	56.5	56.8	54.2	56.8	43.7	62.9
Alternating hills and lowlands	Aileron	42.3	59.7	58.4	42.3	56.4	55.1	48.4	51.7	55.0	47.2	75.3
	Allua	33.1	62.6	48.8	43.5	50.0	47.2	41.8	48.1	49.4	41.9	73.2
	Bond Springs	45.9	63.9	57.7	48.4	57.3	53.5	46.4	54.2	57.8	53.2	68.9
	Cavenagh	39.5	57.3	41.7	35.2	51.9	47.5	35.3	41.1	46.0	41.1	77.6
	Chisholm	41.2	56.3	52.8	46.3	54.9	51.4	44.2	52.3	55.9	49.2	66.6
	Coghlan	46.9	68.7	39.1	32.8	55.4	46.9	38.5	40.3	40.5	42.1	55.3
	Gillen	38.6	62.5	50.8	44.2	51.3	47.3	40.7	47.6	48.8	42.2	70.7
	Hann	41.0	57.2	48.7	42.9	51.9	47.7	47.2	49.0	53.2	41.4	66.8
	Hogarth	22.2	50.0	31.8	33.1	37.2	37.2	46.1	36.5	37.7	26.7	68.0
	Ilbumric	46.5	62.8	57.3	46.2	54.5	51.0	47.8	53.5	57.7	45.0	64.3
	Ilgulla	25.3	51.7	37.1	39.9	41.0	39.2	46.7	41.3	42.5	33.4	57.5
	Kurundi	35.7	54.4	44.8	37.9	49.8	42.1	42.2	45.1	49.4	36.4	62.5
	Napperby	48.9	63.4	52.2	38.0	54.5	46.8	36.7	51.1	56.4	42.9	69.2
	Rumbulara	28.3	51.7	28.9	25.8	41.0	36.0	29.3	35.2	39.3	27.7	59.8
	Stokes	39.8	58.9	49.5	41.5	49.2	44.9	34.9	42.7	43.2	34.0	68.8
	Table Hill	37.5	53.8	50.6	32.3	42.9	40.3	40.3	42.8	48.1	36.4	71.4
	Weldon	53.6	72.1	60.0	48.5	59.4	52.7	43.9	53.8	59.4	48.4	72.0
Sparse low tree country	Alcoota	38.4	50.9	51.1	39.9	49.9	46.2	42.2	48.2	52.9	40.8	66.1
	Anderinda	24.2	37.7	34.4	21.5	34.5	29.6	33.1	33.4	40.0	22.6	61.7
	Barrow	41.8	60.9	50.9	37.8	49.3	49.7	37.5	49.8	56.1	35.3	60.9
	Ennugan	53.6	64.3	55.8	48.3	57.2	52.4	42.7	53.5	58.2	44.3	70.0
	Indiana	53.8	71.4	58.0	48.7	61.5	62.6	54.3	53.5	58.6	53.4	71.1
	Ryan	32.7	42.7	39.3	29.5	45.3	40.6	37.9	40.8	46.9	32.5	64.8
	Warburton	50.5	64.3	50.3	31.8	50.8	40.7	27.6	44.2	51.5	36.6	68.3
Mulga	Boen	49.3	63.4	59.7	47.8	55.9	54.8	48.1	55.5	58.6	47.5	71.1
	Bushy Park	49.7	66.9	59.5	50.6	58.4	57.2	50.9	57.2	59.4	50.4	72.7
	Karee	48.8	66.0	51.8	48.1	60.7	60.3	50.5	56.4	54.3	47.6	77.6
	Tietkins	53.8	67.8	57.6	56.0	67.2	66.9	55.8	61.0	58.9	52.4	82.1
Mulga mixed with spinifex sand plain	Alinga	46.3	68.3	61.8	50.5	57.3	54.2	52.4	55.6	60.0	48.4	69.0
	Leahy	45.8	56.8	55.4	43.5	52.2	49.5	50.4	53.0	60.5	51.8	72.2
	Lindavale	47.7	61.0	48.4	44.5	59.4	54.1	42.4	50.8	50.0	43.7	74.3
Witchetty bush	Muller	39.2	58.2	54.0	43.2	45.7	40.4	33.1	46.6	50.8	38.3	76.8
	Outounya	43.2	61.0	45.7	38.2	56.8	52.0	39.7	46.0	50.0	45.2	79.6
Gidgee	Delny	37.0	60.1	50.9	36.8	44.4	42.8	40.3	45.5	48.1	38.3	65.0
	Lucy	20.9	48.8	39.0	34.5	38.5	38.3	48.3	37.8	37.7	25.0	72.0
	Ooratippra	18.8	38.7	39.2	28.1	37.1	36.6	53.2	33.8	35.8	26.1	64.7
	Pulya	38.3	35.6	50.5	31.0	49.5	44.4	29.1	35.6	37.2	35.0	56.8
	Ringwood	39.1	48.2	53.5	42.2	53.1	47.9	38.3	43.0	47.7	41.3	62.8
Variable sparse low vegetation	Titra	43.8	61.6	51.6	44.0	54.5	49.3	41.7	51.1	50.0	43.0	71.7
	Woolla	59.0	61.2	62.3	57.4	65.1	61.5	58.3	63.9	64.3	54.2	70.9

Pasture land	Land system	Year (Epoch)										
		1972	1980	1985	1988	1989	1991	1992	1995	1998	2000	2002
Short grass - Young alluvia	Adnera	55.3	58.6	52.1	43.1	52.7	52.8	53.7	52.4	54.2	43.7	65.2
	Ammaroo	32.9	47.5	35.3	28.3	38.1	37.1	47.1	34.2	46.1	31.9	59.7
	Deering	37.7	49.7	41.3	31.1	45.7	38.2	27.3	38.1	39.2	28.7	59.3
	Finke	29.1	44.6	39.7	30.9	44.9	37.0	27.3	34.5	40.3	34.2	61.5
	Hamilton	35.0	51.6	50.1	39.8	49.8	46.2	35.1	48.2	49.1	38.8	67.9
	Kanandra	51.0	68.4	58.9	48.6	58.3	53.1	49.8	55.1	59.1	51.7	71.4
	McGrath	38.3	48.7	46.4	36.7	50.9	45.5	44.0	46.5	53.3	41.2	65.6
	Sandover	43.4	55.8	49.6	41.9	52.4	50.5	47.2	49.5	54.8	41.9	67.7
	Todd	23.9	55.1	51.3	27.4	47.3	39.7	22.2	35.3	46.4	37.1	61.4
	Utopia	51.8	60.4	57.8	51.7	59.6	58.7	59.0	60.5	64.8	52.2	64.0
	Woodduck	49.4	61.9	52.9	48.9	55.5	54.3	52.7	55.4	60.4	48.5	68.0
Bluebush country	Ebenezer	35.0	46.3	35.6	30.8	47.8	39.9	28.9	37.7	37.4	30.3	71.3
	Lilla	30.9	50.1	28.1	22.7	45.7	41.6	27.3	32.1	36.7	25.5	65.4
	Renners	30.1	55.7	34.5	35.7	40.8	34.8	33.6	42.0	42.2	31.5	69.9
Saltbush country	Endinda	23.4	36.4	23.0	22.2	41.0	30.5	27.9	31.0	35.2	26.6	65.8
	Kalamerta	46.0	62.0	46.0	42.1	56.5	55.5	45.2	49.3	50.0	41.2	78.1
	Kulgera	45.7	61.2	46.2	41.6	56.7	53.2	42.3	51.2	49.9	48.2	77.0
	Peebles	40.2	63.0	29.3	29.0	49.0	45.4	35.0	39.1	43.7	32.5	58.6
Mitchell grass	Ambalindum	30.4	52.9	42.0	29.7	39.9	36.3	33.2	35.7	46.2	41.4	59.3
	Undippa	32.7	54.1	47.2	33.2	41.8	40.0	36.6	42.1	47.5	38.5	61.7
Open country with sclerolaena pastures	Chandlers	33.0	53.1	36.1	34.4	39.1	33.0	30.6	39.8	39.7	28.8	67.5
Spinifex	Amulda	23.9	57.6	46.0	33.8	43.6	40.6	30.1	40.4	45.2	34.3	69.8
	Angas	35.6	59.0	44.4	37.1	52.0	44.4	36.0	41.3	43.6	37.4	70.3
	Ewaninga	39.5	62.6	55.6	46.1	48.9	45.0	42.0	53.3	55.2	43.3	80.0
	Middleton	38.7	61.6	47.7	40.9	51.6	47.8	38.7	45.3	46.7	39.8	67.6
	Simpson	36.9	56.8	45.3	40.3	49.7	46.6	40.9	45.4	47.7	36.9	65.5
	Singleton	40.5	55.4	45.1	42.0	50.9	48.0	43.6	47.6	52.3	41.8	58.9
	Tennant Creek	47.5	60.0	54.5	47.8	55.1	53.8	45.7	55.8	60.5	44.9	62.9
	Wonorah	31.9	45.0	29.7	36.4	39.6	36.1	36.9	42.0	42.4	42.5	52.2
Salt lake	Amadeus	37.4	49.6	37.4	35.4	46.7	38.3	30.8	40.4	41.8	32.9	61.4

Appendix 1d: Wind erosion maps of the southern Northern Territory (2000–2004)

High resolution wind erosion maps of the southern Northern Territory are provided for comparison with the vegetation cover maps. High resolution wind erosion maps of the southern Northern Territory could be compared with vegetation cover maps of the kind shown in Appendix 2, Figure A1.4. Wind erosion rate is measured the Dust Storm Index (DSI).

The DSI used in these maps is calculated using the following equation,

$$DSI = \sum_{i=1}^n [(5 \times SD) + MD + (0.05 \times LDE)]_i$$

Where:

DSI = Dust Storm Index at n stations where i is the ith value of n stations for i=1 to n. The number of stations (n) is the total number of stations recording a dust event observation in each year.

SD = Severe dust storm (daily maximum weather codes: 33, 34, 35)

MD = Moderate dust storm (daily maximum weather codes: 30, 31, 32 and 98)

LDE = Local dust event (daily maximum weather codes: 07 and 08)

Weather code 09 events have been reassigned as 07s or 30 to 35s according to recorded visibility.

The interpolation method used was the Natural Neighbour default setting used in the Vertical Mapper component of MapInfo Professional. The colour profile 'DSI-annual-total-colour_2005_draft1.vcp' was used for the DSI shading.

Southern Northern Territory maps of annual total DSI for 2000–2004

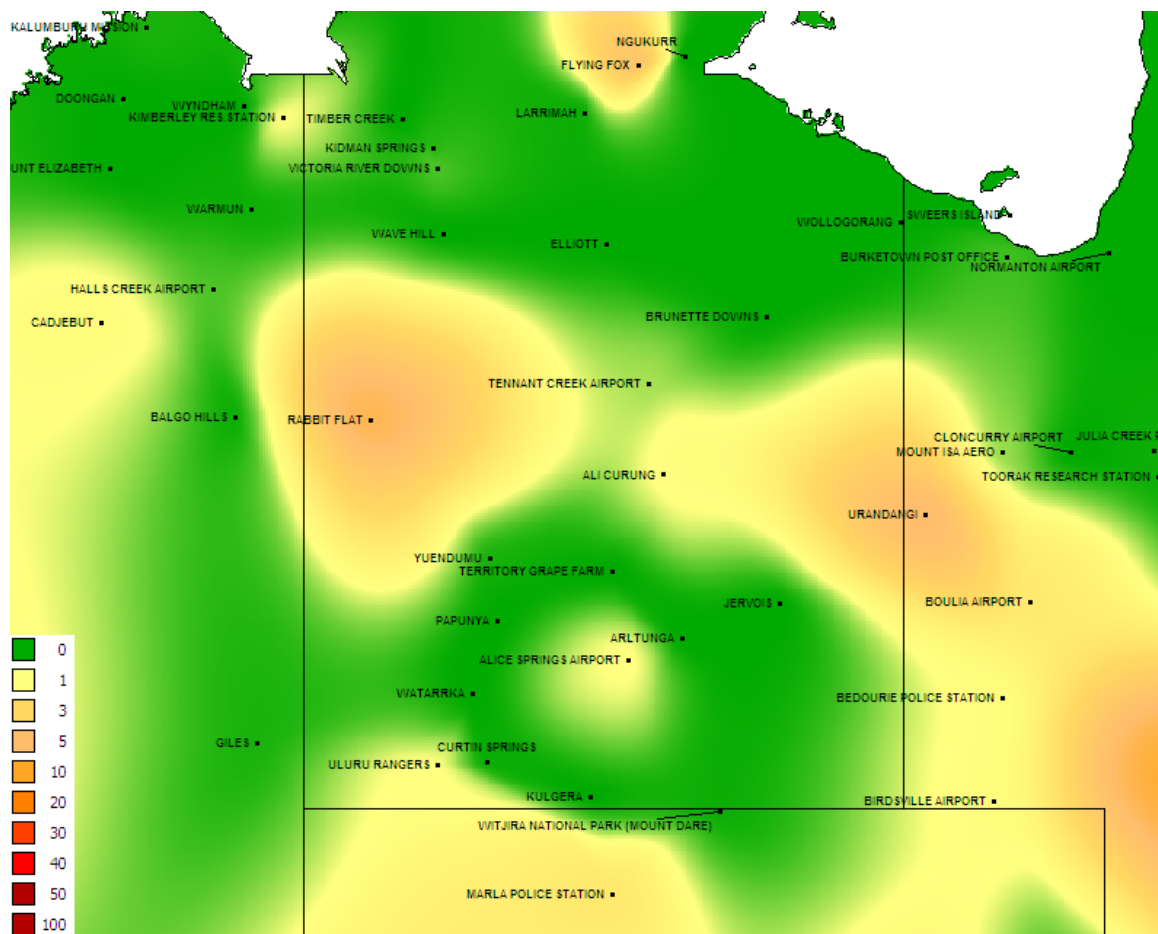


Figure A1d.1: Annual total DSI for the southern Northern Territory in 2000

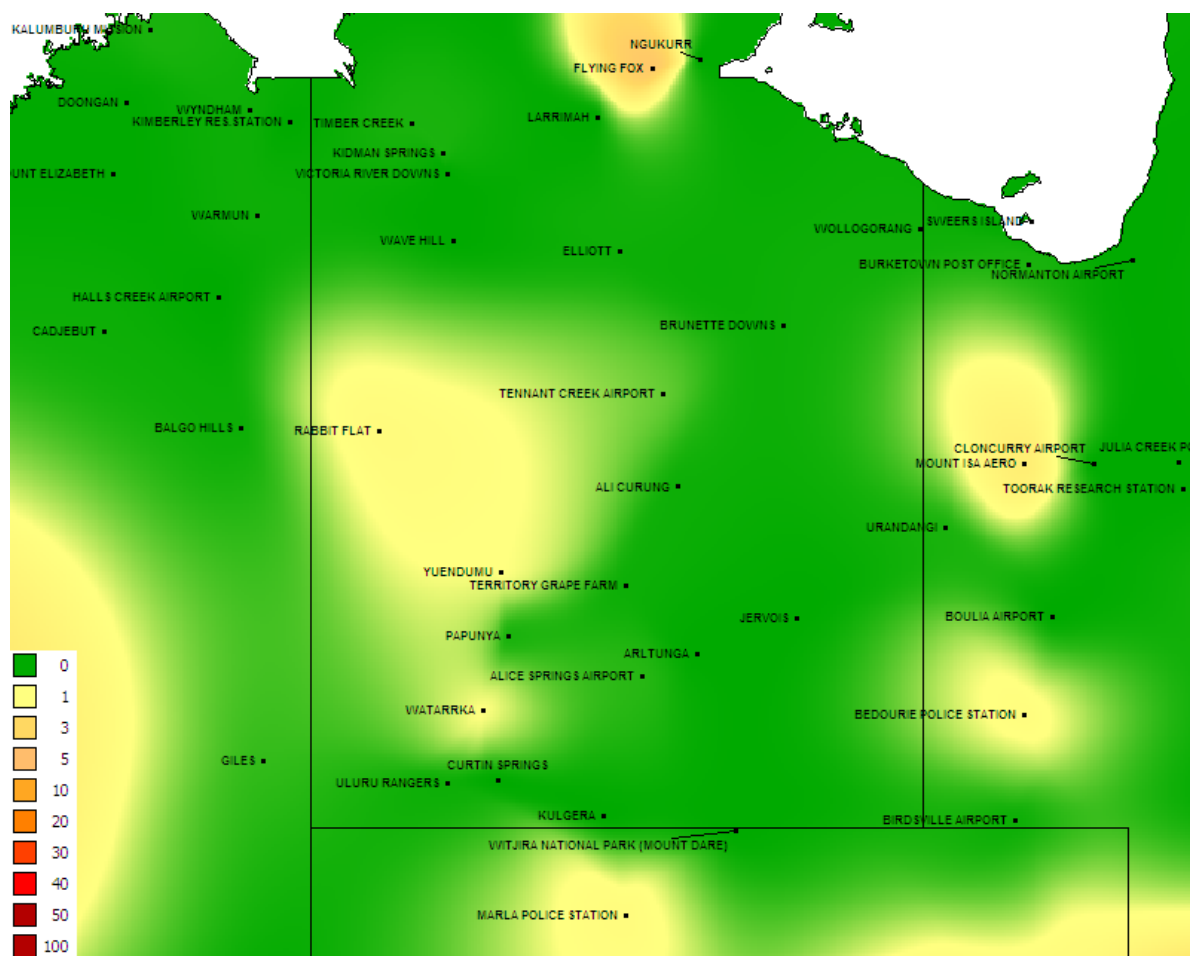


Figure A1d.2: Annual total DSI for the southern Northern Territory in 2001

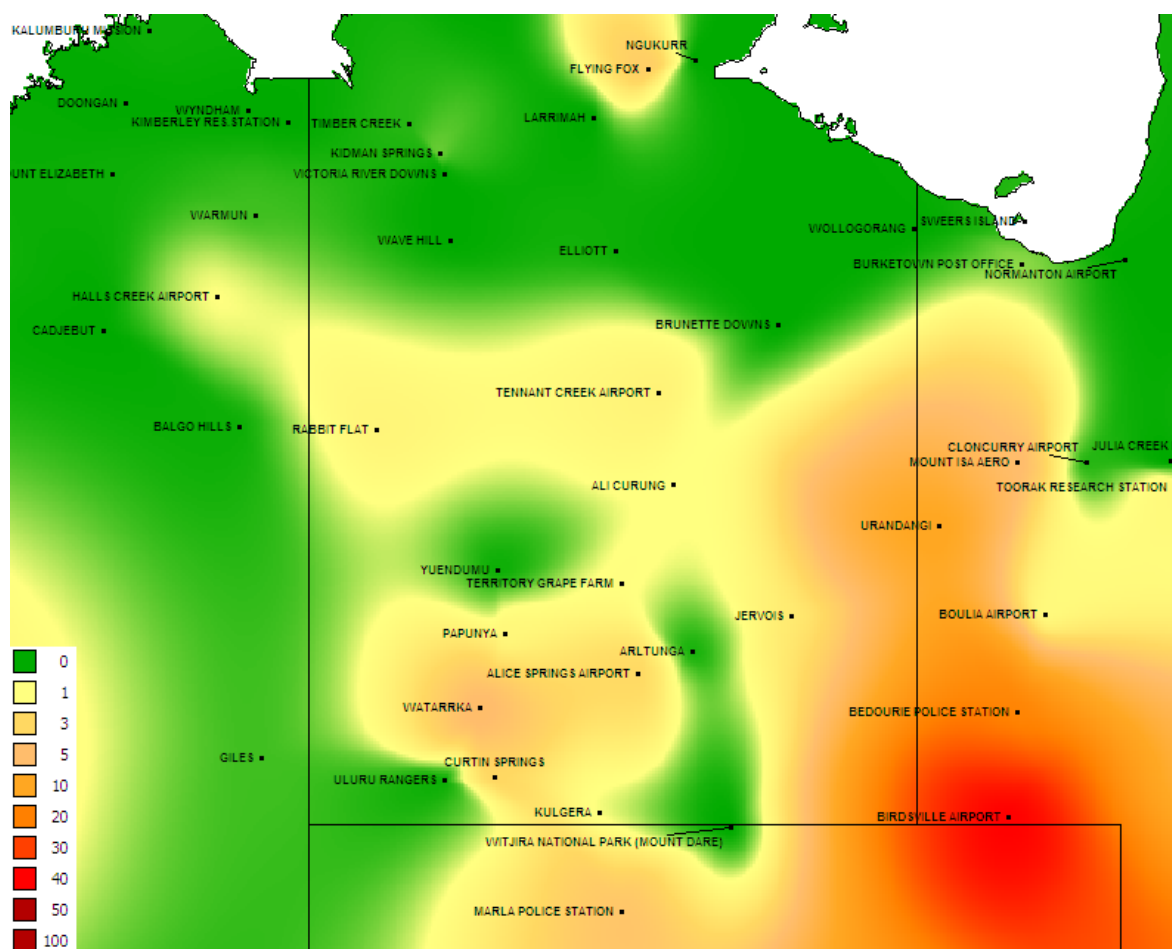


Figure A1d.3: Annual total DSI for the southern Northern Territory in 2002

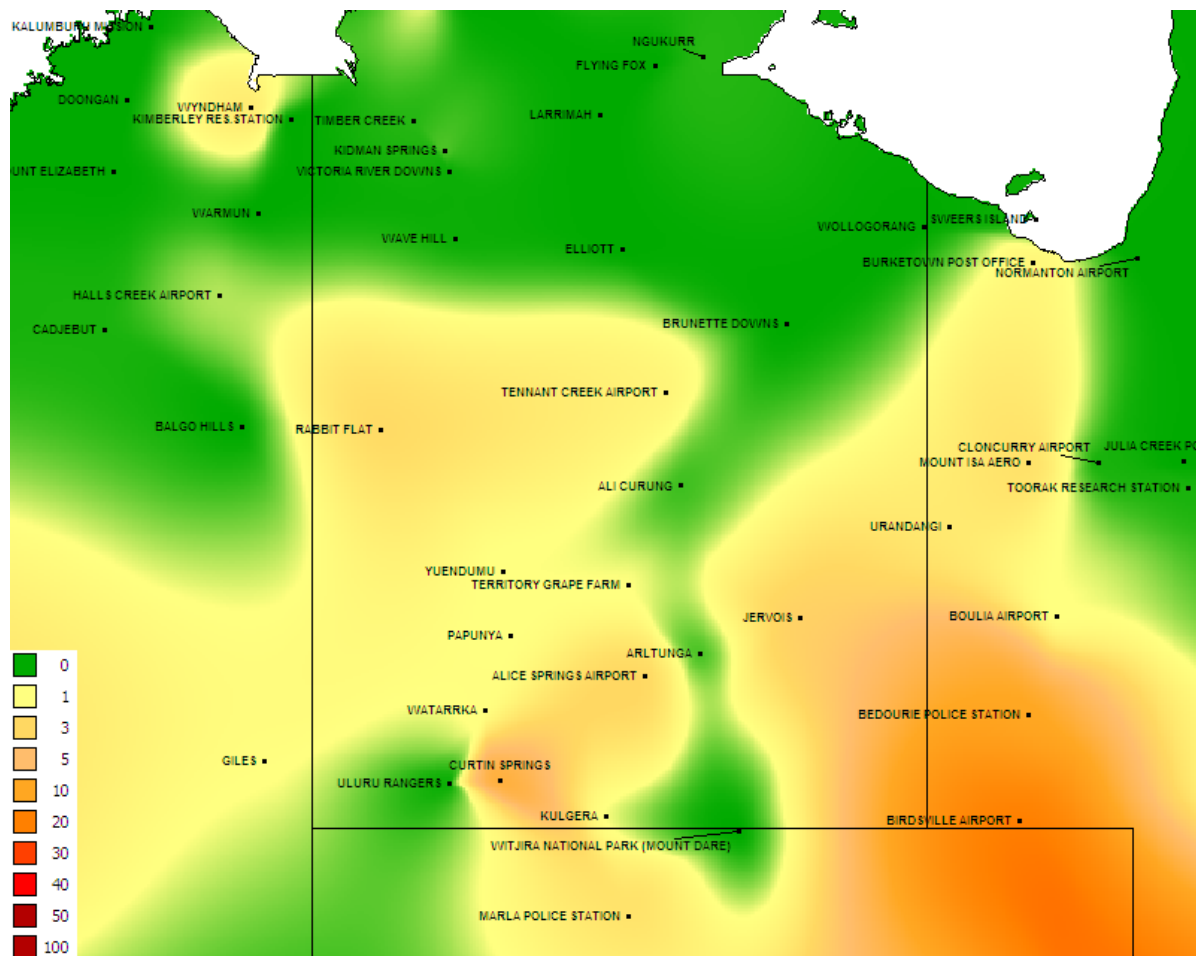


Figure A1d.4: Annual total DSI for the southern Northern Territory in 2003

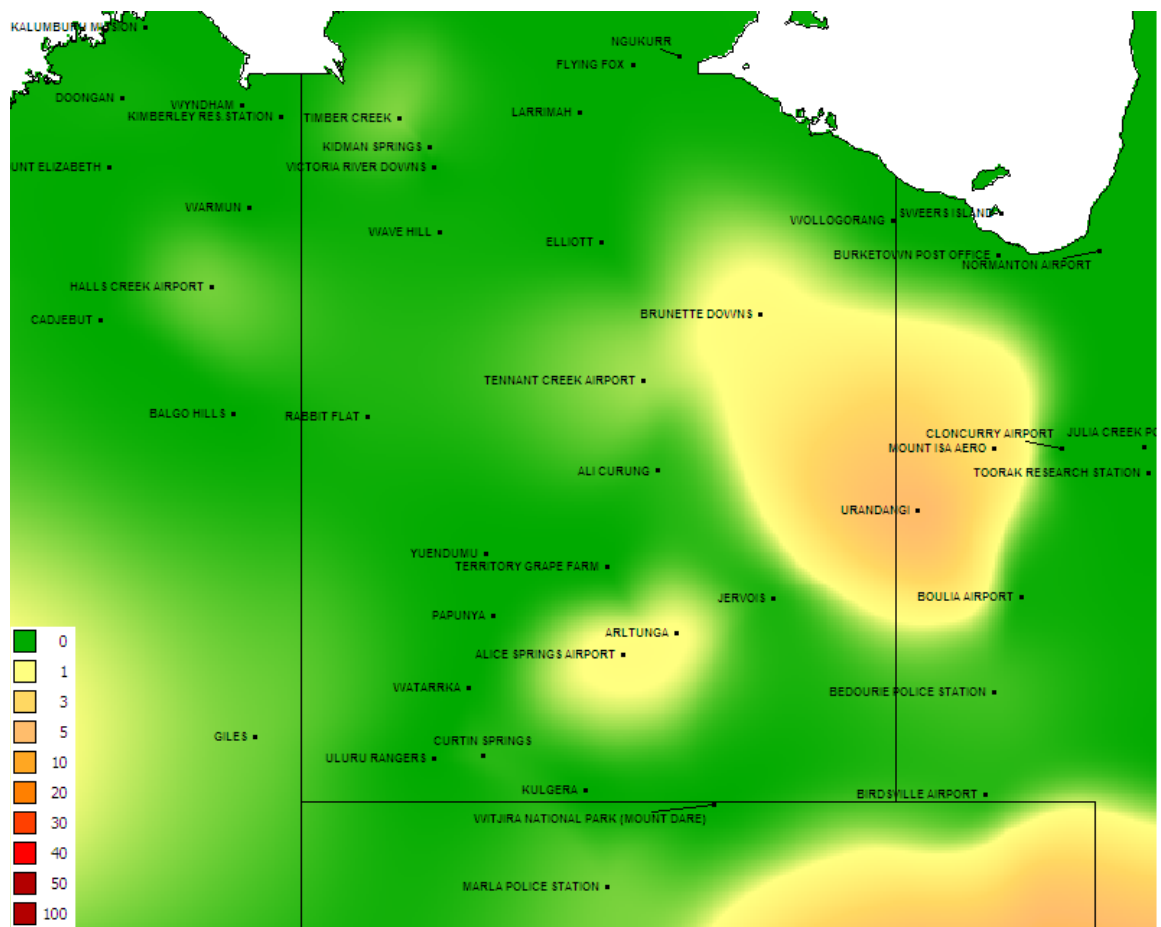


Figure A1d.5: Annual total DSI for the southern Northern Territory in 2004

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