TROPICAL SAVANNAS CRC
Cooperative Research Centre for Tropical Savannas Management

An Evaluation of 250m MODIS Satellite Data for Monitoring the Condition of Tropical Savanna Rangelands

Victoria River District Northern Territory

Kate Richardson (2006)

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Executive Summary

This 12 month study was undertaken to evaluate whether MODIS satellite data is able to provide useable data for land management. The project looked at B1 and B2 MODIS data.

Current monitoring techniques provide monitoring information between years, at the end of the growing season. For improved commercial and sustainable management decisions, information is required throughout the year, when management decisions can be altered to suit current conditions.

A new generation satellite – Moderate-resolution Imaging Spectro-radiometer (MODIS) offers a possible solution, with increased spectral and temporal capabilities, to provide information to further enhance the current monitoring program.

The project was undertaken in the VRD pastoral district of the NT upon the Victoria River Downs property. Two pastorally significant land types were assessed using the MODIS data; the basaltic black soil plains and the limestone calcareous red soils.

A total of 70 500m x 500m ground sites representing varying condition classes were used for the project, 30 located upon red soils and 40 upon black soils.

Ground sites were classified upon the presence/absence of perennial grass species over the site. This is consistent with the Landscape Function Analysis (LFA) approach of Tongway and Hindley 1995.

The project determined that MODIS data is able to detect differences in rangeland condition. Changes or variation in cover levels, thus condition, are most apparent towards the end of the dry season when vegetation cover is senescent.

B1 and B2 data were found to be highly effective and efficient in detecting differences between condition classes upon the black soil plains of the Victoria River Downs property. Differences were detected within the season, from month to month of the dry season.

Application to red soil landscapes was found to be less effective and highlighted the complexities of using satellite data for range management upon light coloured soils.

The use of visible red and near infrared data as surrogates for ground vegetation cover in basaltic landscapes has proved effective and able to be integrated within the current monitoring program.

Introduction

The management of rangelands is very diverse and complex. Vastness, sparse populations and harsh conditions are major factors that contribute to the lack of data and information, which consequently affects the monitoring of rangeland condition. Satellite based monitoring techniques have been developed and utilized extensively throughout the rangelands of Australia (Bastin et al. 1993, Ludwig et al. 2000).

Within the Northern Territory, satellite based monitoring techniques are being used to assess the conditions of rangeland utilised by the pastoral industry in the Victoria River District (VRD) and Sturt Plateau regions (Figure 1). Landsat Multi Spectral Scanner (MSS) and Thematic Mapper (TM) data are combined with ground based data to provide information on landscape cover change and processes.

Methods developed by Wallace et al. (1994) and Wallace and Thomas (1998), to detect rangeland changes through a series of Landsat scenes has resulted in the application and further development by Karfs et al. (2000) to implement a government directed satellite based monitoring program.

A new generation satellite – Moderate-resolution Imaging Spectro-radiometer (MODIS) offers a possible solution, with increased spectral and temporal capabilities, to provide information to further enhance the current monitoring program.

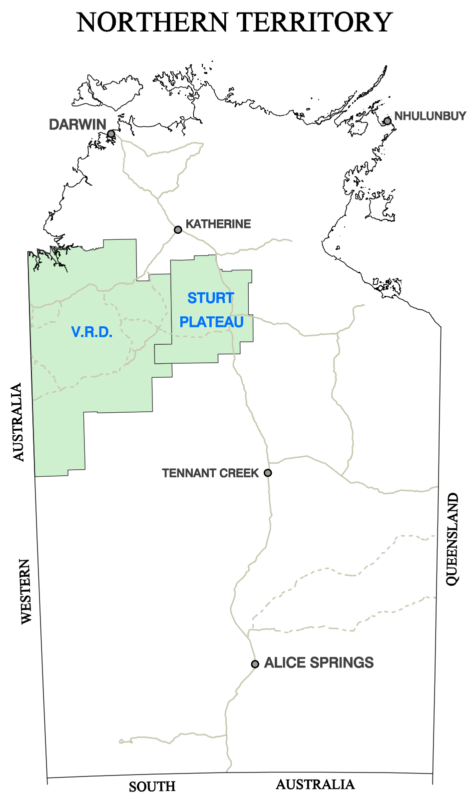


Figure 1. Location of VRD and Sturt Plateau Regions

The most significant aspect of MODIS is the capacity to deliver near-real time information and to deliver this information over a very wide area. All products and data received from MODIS have been corrected for geometric, radiometric and atmospheric distortions, to provide data and products that are directly useable (Zhan et al. 2002).

Background

The Northern Territory's satellite based monitoring program has proved effective in providing land condition and landscape processes information with respect to grazing effects for the VRD and Sturt Plateau region (Karfs et al. 2000).

This study is part of a collective drive of government agencies throughout Australia utilising remote sensing technologies to monitor land cover change as part of their respective environmental monitoring and management programs.

Landsat data has proved successful in determining the rate of tree clearing in Queensland (Danaher et al. 1998), NOAA-AVHRR data is used to model pasture growth of rangelands (Hall, 1999) and NDVI indices used to determine seasonal conditions throughout Australia (Cridland and Fitzgerald, 2001). Recently the Australian Greenhouse Office (AGO) used a time series dataset of Landsat MSS and TM data to map changes in tree cover over time and determine levels of clearing across the nation (AGO, 2002)

The project provided an opportunity to evaluate MODIS data and its application to the wet-dry tropics – in particular land cover change of rangelands. To date, most work and application of MODIS has focussed upon US rangelands (Reeves et al. 2001) validation of algorithms and products, atmospheric corrections and global land cover mapping, which MODIS was developed. The integration of MODIS data with an existing satellite based monitoring program provides an opportunity to test the new data in an applications, rather than experimental environment.

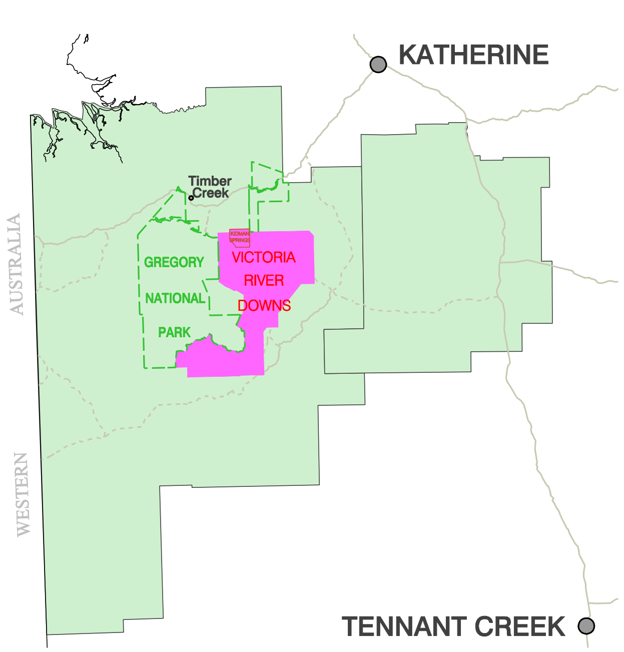


Figure 2. Location of VRD and Kidman Springs Station

Rangeland Condition

For the purpose of the study the definition of rangeland condition will be based upon landscape function. Landscape function describes the distribution of plants (within a landscape) that have the capacity to capture, retain and use natural resources (water and nutrients) (Tongway and Ludwig, 1997). A functional landscape, i.e. good condition, consists of many perennial plants, which act as sinks to collect water and nutrients, thus retaining resources within the landscape. On the other hand, a dysfunctional or poor condition landscape has very few perennial plants resulting in few sinks to collect water and nutrients so consequently, are lost from the landscape.

This definition is being used, as it is the basis of landscape condition used throughout the satellite-monitoring program in the Northern Territory (NT).

The study area is located within the Victoria River District (VRD) of the Northern Territory (Figure 2). Victoria River Downs is one of the oldest properties in the region and since 1989 has been under the management of the Heytesbury Beef Group. During this time stocking and utilisation rate changes have been the focus of management techniques on the property. The VRD region and Victoria River Downs has been the centre of many rangeland studies resulting in 'data rich' areas with extensive vegetation, soil and land resource and cattle production data available.

Objectives

The overall goal of the project is to evaluate the capabilities of 250m MODIS data for mapping changes to rangeland condition. This will be undertaken upon the Victoria River Downs property within the VRD of the NT.

Essentially the project was determining if the 250m MODIS visible red and the near infrared (NIR) data provided accurate and useable information for land condition assessment in the rangelands of the Victoria River District, NT.

The project is a comparative study of 250m MODIS red band and NIR data over a 'wet-dry-wet' season sequence with ground based and ancillary data.

Methods

Study Area

The study was undertaken upon the Victoria River District property, Victoria River Downs. The Victoria River District, a pastorally significant region, is located in the north-west of the NT. Covering approximately 125000km^2, it comprises of sandstone and limestone ranges, basalt hills and red and black soil plains. The climatic conditions range from high rainfall tropical regions to arid inland desert plains. (Stewart et al, 1970)

Victoria River Downs is located in the eastern part of the district and is one of the oldest stations in the region. Historically and today, this district is an important pastoral region due to the vast area of perennial grasses on black basaltic plains.

Land resources

Two pastorally significant land types were examined, the basaltic black soils and limestone calcareous, red soils.

The basaltic land system which consists of the Antrim and Wavehill land systems cover 56% of the property and provide the largest useable areas for pastoral activities and supports the largest productive pasture community.

The red soil areas, limestone calcareous land systems are predominantly low to mid high open woodland with shallow soils and some surface rock. The red soil areas of the VRD are dominated by grass species that are palatable, nutritious and digestible.

Landscape stratification

Stratification is an important step when assessing satellite data for rangeland monitoring and validation with ground data (Graetz 1987; Friedel et al. 1993; Pickup et al. 2000). The site data was stratified between two pastorally significant landtypes upon the property – the limestone-calcareous red soils and the basaltic derived black soils. Stratification was based upon 1:100 000 landunit (McLeod and VanCuylenburg, *in prep)* mapping of the property.

The project area was stratified into two pastorally important landtypes based upon lithology and landform characteristics. These were landscapes formed upon basalt parent material, the black soils and limestone calcareous material, the red soils. Stratification of the project was based upon previous works (Karfs et al, 2000) which had determined that darker coloured soils were associated with basaltic soils and lighter coloured soils were associated with the red soil types.

Satellite data

MODIS (or Moderate Resolution Imaging Spectro-radiometer) is a new generation satellite data which provides information and images of the earth every day. Detectors measure 36 spectral bands and acquire data at three spatial resolutions – 250m, 500m and 1km. The first 7 bands of the data are specifically related to land properties and capabilities, with only the first two bands, B1 and B2 having a spatial resolution of 250m.

Fortnightly acquisition of cloud free 250m MODIS data from January 2003 to January 2004 was used. This included the visible-red band (B1) and the near-infra-red band (B2) as listed in Table 1.

Imagery was sourced from the TERRA satellite to provide consistency with departmental Landsat datasets. For the months of the wet season only a monthly image was selected due to the weather conditions and high levels of cloud cover experienced during this time.

The MODIS imagery supplied had been geometrically corrected using information from on-board GPS and spacecraft ephemeris and altitude information. It was also radio-metrically corrected using the International MODIS Atmospheric Infrared Sounder (AIRS) Processing Package (IMAPP) (Strabala et al, 2002). Hence the MODIS data was not calibrated to a base or reference image as atmospheric corrections were applied upon collection by the sensor.

The MODIS sensor possesses an extensive on-board capability for radiometric and spectral calibration. The calibration systems include spectro-radiometric calibration assembly (SCRA), solar diffuser and solar diffuser stability monitor for short wavelength data and for longer wavelength data, a blackbody for thermal band calibration. The MODIS sensor has included specific bands for atmospheric sensing which provides for atmospheric correction and an estimation of surface directional reflectance (Zhan et al, 2002).

Table 1. Acquisition dates of 250m MODIS data

Sensor	Acquisition Date
Terra	3 Jan 2003
	4 Feb 2003
	13 March 2003
	24 March 2003
	9 April 2003
	25 April 2003
	2 May 2003
	11 May 2003
	20 May 2003
	29 May 2003
	5 June 2003
	14 June 2003
	30 June 2003
	16 July 2003
	1 Aug 2003
	17 Aug 2003
	2 Sept 2003
	16 Sept 2003
	4 Oct 2003
	20 Oct 2003
	1 Nov 2003
	19 Nov 2003
	17 Jan 2004

Ground data

Site data utilised consisted of field observations, permanent monitoring sites and local knowledge from pastoralists. To provide consistency between the different types of site data, classification of the sites was necessary.

From previous studies of satellite data and land condition monitoring it has been determined that cover levels are identifiable and measurable indicators (Karfs et al, 2000). Hence the data was classified upon the presence/absence of perennial grass species over the site. This is consistent with the Landscape Function Analysis (LFA) approach of Tongway and Hindley 1995. This definition has been adopted by the current rangeland monitoring program developed and utilized by the NT Government. Thus, poor sites will have very few to no perennial grass species, while sites in good condition are dominated by perennial grass species.

Due to the resolution of the MODIS satellite imagery, it was necessary to select sites with a minimum size of 500m x 500m and no larger that $1km^2$ (these sized sites are in the minority). As a consequence, it resulted in sites being in extremely poor or low condition and areas with very high or good condition to provide near as possible homogeneity across the site.

As a result a total of 70 sites were located across the property. For the analysis of red soils, a total of 30 sites were selected, 15 representing areas of good condition and 15 representing poor condition. For the black soils, a total of 40 sites were selected, 20 each for good and poor condition areas.
A higher number were selected upon the black soils as it makes up a larger proportion of the property.

Analysis

The spectral responses for the MODIS data over time were plotted for the sites and the land-systems to provide indication of seasonal responses, site variations and variations in response which may relate to cover/condition. These were generated using the mean value of the B1 and B2 MODIS data.
The data were subjected to analysis of variance using the Statistica statistical package and means were separated using least significant differences ($P<0.05$).

Results

The project examined associations between ground measured condition (cover types) and sequences of MODIS data.

In order to determine if 250m MODIS visible red and the near infrared (NIR) data provided accurate and useable information for land condition assessment, the following questions were examined.

1. Is a significant difference able to be distinguished between good and poor condition sites within the study area?
2. Is a significant difference able to be distinguished between red and black soil types? and
3. Is a significant difference able to be detected between good black and poor black sites? And a difference between the two condition classes for the red soil types?

For each sub question, two time trace graphs were generated and a table of results. For the first question, both graphs and the table have been included, for the remaining sub questions, only the tables have been included and the graphs appended to the end of the report.

NDVI was not assessed, as previous studies and authors have found it ineffective in North Australian environments for rangeland monitoring (Pickup et al. 1993, Ringrose et al. 1989)

The effect of land condition

Time traces for each condition class, good and poor were generated from the mean values of the B1 and B2 data, figure 3 and 4. These were generated from combining all good sites, regardless of soil type (red or black) and analysing as one class. This was repeated with the poor site data. Results from the analysis are presented in Table 2.

As depicted in the time traces, the cover levels vary throughout the year in relation to the condition class. The good condition sites have, as expected a higher cover level than the poor condition sites. This is consistent with the vegetation curing/cycle of vegetation in the wet tropics.

During the wet season, January to April, vegetation cover is high, lush, green experiencing vigorous growth. Discrimination between areas of poor and good condition is very difficult due to high spectral responses across the region and all vegetation condition types. As the vegetation begins to hay-off and lose moisture content, differences between the vegetation conditions and cover levels become apparent.

Analysis of the curves and mean values determined that differences between the two condition classes were observed towards the end of the dry season.

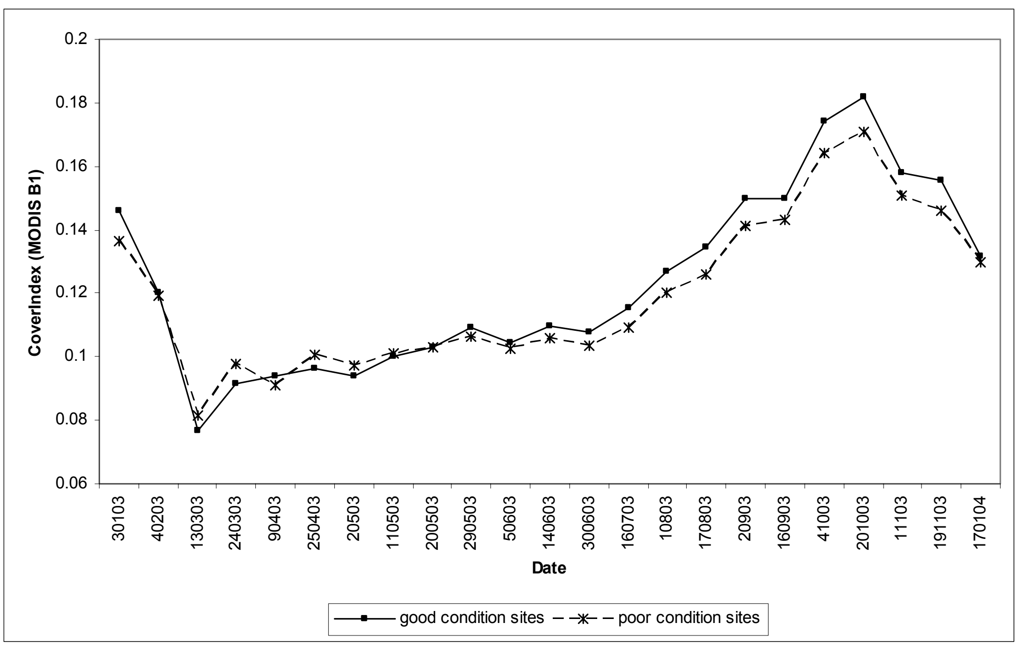


Figure 3. Time trace of each condition class, good and poor from B1 MODIS data. Discrimination between good and poor condition during the wet season is difficult due to high levels of green cover. As the dry season prevails and vegetation cover loses moisture content, differences between poor and good condition sites become apparent.

Table 2. Statistical results of discrimination between condition classes for B1 and B2 MODIS data using least significant differences (*P<0.05*)

MODIS B1 data - condition Date	P value	P<0.05	MODIS B2 data P value	P<0.05
30103	0.003044	*	0.047228	*
40203	0.782560		0.958433	
130303	0.051532		0.263757	
240303	0.014676	*	0.779536	
90403	0.304374		0.395538	
250403	0.038844	*	0.716838	
20503	0.105181		0.954682	
110503	0.681034		0.260747	
200503	0.965113		0.199799	
290503	0.292084		0.014649	*
50603	0.454696		0.078767	
140603	0.255353		0.011886	*
300603	0.187442		0.004209	*
160703	0.071303		0.003272	*
10803	0.058151	*	0.002094	*
170803	0.012382	*	0.000316	*
20903	0.009580	*	0.000471	*
160903	0.037018	*	0.006567	*
41003	0.004546	*	0.005925	*
201003	0.001163	*	0.003799	*
11103	0.246959		0.078552	
191103	0.006271	*	0.031454	*
170104	0.545065		0.221287	

The B1 data was able to detect significant differences between the condition classes for the period 17th August to 20th October 2003. The B2 data was able to determine differences earlier in the season, 14th June through to 20th October 2003. From these results, it would indicate that further stratification or work would not be required, but as noted by other authors and studies (Ringrose *et al*, 1989) these results are highly influenced by soil reflectance values, due to the nature of the environment, rather than by the vegetation cover levels.

Late dry season imagery, where differences are apparent, is characterised by high reflectance values for hayed-off grass (present upon black soil land types) and light coloured soil and bare rock. This can provide confusion in the interpretation of reflectance values for areas with high and low grass cover for land types not dominated by black soil grasslands (Wallace and Thomas, 1998).

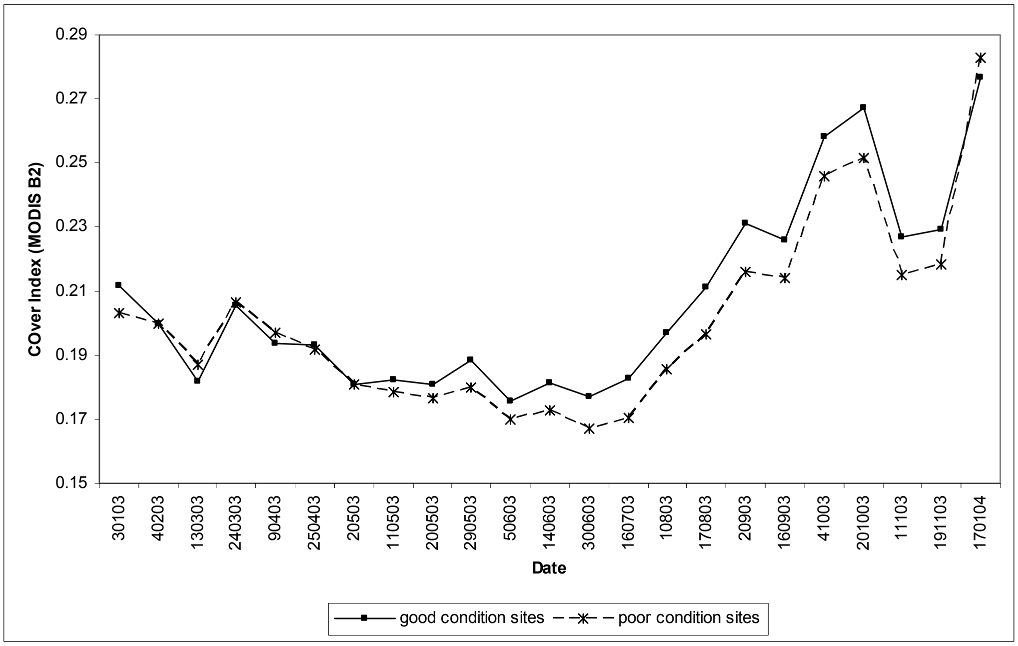


Figure 4. Time trace of good and poor condition classes from B2 MODIS data. Discrimination between good and poor sites during the wet season is difficult due to high levels of green cover. Separation between sites of varying condition is detectable as vegetation cover begins to hay off.

The effect of soil

To accommodate the variation in land types and thus reflectance values, the sites were classified according to soil type. All black sites and all red sites were combined, regardless of condition to determine if soil type had an effect upon reflectance values.

As highlighted in Table 3, B1 data was found to be most successful in differentiating between red and black soil types. Visible red band data has been used in many applications to discriminate between soil and vegetation within open rangeland and arid environments (Graetz, 1987, Graetz and Gentle 1982).

Table 3. Statistical results of discrimination between soil classes for B1 and B2 MODIS data using least significant differences (*P<0.05*)

MODIS B1 data - soil			MODIS B2 data	
Date	P value	P<0.05	P value	P<0.05
30103	0.003208	*	0.042106	*
40203	0.022624	*	0.000009	*
130303	0.102132		0.408633	
240303	0.939795		0.864722	
90403	0.003122	*	0.579430	
250403	0.032162	*	0.008458	*
20503	0.000041	*	0.003184	*
110503	0.000203	*	0.367125	
200503	0.000000	*	0.213482	
290503	0.000000	*	0.283816	
50603	0.000000	*	0.474477	
140603	0.000000	*	0.518879	
300603	0.000000	*	0.402528	
160703	0.000012	*	0.669983	
10803	0.000000	*	0.888012	
170803	0.000103	*	0.332845	
20903	0.000104	*	0.141877	
160903	0.001285	*	0.060011	
41003	0.001314	*	0.003837	*
201003	0.010252	*	0.000803	*
11103	0.014102	*	0.489896	
191103	0.144227		0.000023	*
170104	0.347557		0.844488	

The soil/condition effect

To assess and highlight the importance of stratification of different land types, namely light and dark soils, analysis was performed upon the following stratified data. Sites of black land type were classified into good condition sites and poor condition sites. The same was repeated for red land type condition sites.

Results for the analysis of red soil land types are presented in table 4 and black land types in table 5.

Analysis of the two different soil types provided very different results.

As highlighted in table 4, both B1 and B2 were unable to provide useful information for rangeland management. Both bands were unable to differentiate between sites of good or poor condition. The spectral response for both classes was too similar to provide any useable data or information. This again highlights the complexities of using satellite data for range management upon light coloured soils and in this case, red soil types.

Table 4. Statistical analysis results of red soil condition sites for B1 and B2 MODIS data using least significant differences (*P<0.05*)

MODIS B1 data - red soil Date	P value	P<0.05	MODIS B2 data P value	P<0.05
30103	0.617250		0.526935	
40203	0.140533		0.036124	*
130303	0.041945	*	0.006315	*
240303	0.064150		0.020753	*
90403	0.137998		0.766958	
250403	0.095339		0.014083	*
20503	0.190366		0.006720	*
110503	0.223504		0.081356	
200503	0.231032		0.067214	
290503	0.278982		0.068113	
50603	0.257524		0.064535	
140603	0.108933		0.023095	*
300603	0.104876		0.039371	*
160703	0.107692		0.059067	
10803	0.109406		0.032924	*
170803	0.084012		0.103652	
20903	0.168516		0.130633	
160903	0.070841		0.057226	
41003	0.094248		0.102733	
201003	0.127727		0.062904	
11103	0.374165		0.463937	
191103	0.064030		0.151609	
170104	0.773061		0.007603	

In contrast, B1 and B2 data were able to differentiate between poor and good condition sites upon black soils. This is consistent with the current government satellite monitoring program (Karfs et al, 2000) being undertaken with Landsat data. Both B1 and B2 data provide differentiation between condition classes during the dry season, when vegetation is senescent which is also consistent with Landsat monitoring of similar land types.

Within the study, the B2 data proved efficient in detecting differences between good and poor condition classes upon black soils. The traditional red band or B1 data required an extra month, i.e. more time for the vegetation to become senescent for differences to be detected.

Table 5. Statistical analysis results of black soil condition sites for B1 and B2 MODIS data using least significant differences (*P<0.05*)

MODIS B1 data - black soil Date	P value	P<0.05	MODIS B2 data P value	P<0.05
30103	0.000111	*	0.002030	*
40203	0.069111	*	0.026342	*
130303	0.334206		0.532800	
240303	0.105145		0.137339	
90403	0.826810		0.382303	
250403	0.201213		0.011892	*
20503	0.212986		0.041849	*
110503	0.483800		0.002849	*
200503	0.184475		0.003100	*
290503	0.003948	*	0.000049	*
50603	0.005655	*	0.000317	*
140603	0.000346	*	0.000010	*
300603	0.000089	*	0.000005	*
160703	0.000033	*	0.000009	*
10803	0.000003	*	0.000000	*
170803	0.000000	*	0.000000	*
20903	0.000001	*	0.000000	*
160903	0.000001	*	0.000001	*
41003	0.000000	*	0.000000	*
201003	0.000000	*	0.000000	*
11103	0.414644		0.111219	
191103	0.000000	*	0.000006	*
170104	0.592761		0.695623	

These results have provided initial assessment of B1 and B2 capabilities for integration with the current Landsat monitoring program. Both bands are highly efficient in detecting differences between varying condition classes upon black soil types within the season. This data could be integrated with the current program, which provides between season assessments, to highlight hotspot area or areas of change.

This study also highlighted the need for further assessment and analysis upon red soil land types. Both bands were not able to detect significant differences between the various condition classes upon red soils. As previously alluded to, there is not a strong differentiation between light coloured hayed-off vegetation and light coloured soils and has been commented upon by other authors and studies (Ringrose et al, 1989, Graetz 1987).

The complexities of monitoring vegetation cover in north Australian rangelands again has been highlighted by this study and proves to be an issue requiring further work and assessment.

Discussion

Tropical savannas stretch across northern Australia from Broome to Townsville covering an area of 1.9 million km^2, a quarter of Australia's mainland. Pastoralism is the dominant land use, though Aboriginal, mining, tourism and defence activities are significant, generating a total income of $13.5 billion per year. The Savannas are culturally important for Aboriginal peoples and their hugely variable climatic and geomorphological conditions mean that the savannas are havens for bio-diversity.

Rangelands and rangeland condition

Rangeland condition and assessment of condition has been directed by the grazing of rangelands and loosely defined as the 'health' of a grazing area. Methods to determine rangeland condition have been based mainly upon species composition and vegetation biomass to determine forage availability and palatability (Holm, 1998) or the presence or absence of indicator species. Assessments made using vegetation biomass, species composition and vegetation covers have been found to give ambiguous results leading to incorrect assumptions about the state of rangeland condition (McIvor et al. 1995).

To provide consistent accurate assessment of rangeland condition, measurements need to be made upon indicators which are firstly measurable, and then measured repeatedly to provide information on landscape condition (Tongway and Ludwig, 1997).

To address this, Ludwig et al. (1997) put forward the landscape function concept to describe processes undertaken at the landscape level in Australian rangelands. Landscape function describes the distribution of plants (within a landscape) that have the capacity to capture, retain and use natural resources (water and nutrients) (Tongway and Ludwig, 1997). A functional landscape consists of many perennial plants, which act as sinks to collect water and nutrients, thus retaining resources within the landscape. A dysfunctional landscape has few perennial plants to collect resources so are lost out of the system.

Rangeland satellite monitoring

The nature of rangelands both environmentally and economically require a management and monitoring system which is able to provide information over a wide area at a reasonable cost. Remote sensing, namely satellite imagery is suited to the assessment and monitoring of rangelands on a continuos and cost effective basis (Graetz 1987, Tueller 1989 and Pickup et al. 1998).

Landsat data has been used extensively to provide information regarding the surface of the earth and in particular the monitoring of rangelands (Graetz et al. 1976, Wylie et al. 1992, Wallace et al. 1994, Karfs et al. 2000).

Throughout Australia, remote sensing studies have shown there is a relationship between vegetation cover and indices derived from Landsat Multi-Spectral Scanner (MSS) and Thematic Mapper (TM) data. Some of these include early work of Graetz and Gentle (1982) who determined that ground cover and greenness of vegetation were distinguishable in Landsat MSS red and near infrared bands. Graetz et al. (1988) further developed this concept and found that ground cover levels had an inverse relationship to that of the MSS band 2 data.

To provide data in the northern region, Wallace and Thomas (1998) determined Landsat MSS band 2 (red band), was a suitable surrogate for cover and use for detecting cover differences and this has been further developed by Karfs et al. (2000) to provide accurate assessments of rangeland trend and condition.

For the arid zone of Australia, Pickup et al. (1993) devised the PD54 index to determine vegetation cover using visible green and the red band.

Vegetation Indices

In order to monitor and assess vegetation cover levels, vegetation indices have been developed and extensively utilised throughout the remote sensing community. Vegetation indices are spectral transformations of two or more bands to highlight vegetation properties of the surface vegetation cover.

Many of the indices developed and utilised are based upon the red and near infrared (NIR) bands present in satellite data. As a plant develops, the amount of red energy reflected is reduced, as the chlorophyll in the plant increases red light absorption. Reflected NIR light/energy, on the other hand increases with plant development due to scattering processes in healthy leaves (Huete et al. 1999).

Consequently, green vegetation is expected to reflect strongly in the NIR while red reflectance will decrease due to chlorophyll absorption.

The normalised difference vegetation index (NDVI) (a) is a normalised ratio of the NIR and red bands,

(a) $$NDVI = (NIR - red)/(NIR + red)$$

It is able to detect changes in vegetation growth and activity between seasons and inter-annually. The ratioing of the bands provides NDVI with its main strength – ability to reduce forms of multiplicative noise, which is present in multiple bands. The applicability and robustness of the NDVI has been well documented. NDVI has been used extensively as part of global, regional and local monitoring and applied to a variety of satellite sensors including Landsat MSS and TM, NOAA-AVHRR and SPOT (Huete et al. 1999).

NDVI has been used throughout Australia to provide information pertaining to vegetation cover, in particular rangelands and condition of rangeland vegetation cover.

Work undertaken by Cridland, Burnside and Smith (1995) determined NDVI data from NOAA-AVHRR datasets was able to track the health status of the perennial vegetation cover. This required a historical dataset of NDVI values and relied upon local knowledge of vegetation communities and composition, as this study highlighted NDVI value are influenced greatly by vegetation composition, structure and topography and soil reflectance. Further work conducted by Cridland and Fitzgerald (2000) using NDVI in rangelands; with the use of multi date NDVI datasets were able to estimate the amount of perennial vegetation cover at the end of the dry/growing season.

They reasoned rangelands have annual vegetation that is able to with stand harsh conditions by forming seeds and perennial vegetation survives the dry in the vegetative form. This is based upon the assumption that all the green vegetation at the dry season is perennial vegetation.

As NDVI is responsive to vegetation structure, biomass and composition, one-kilometre pixels of NOAA data results in many vegetation types present in one pixel. This presents difficulty in when making spatial comparisons of NDVI values and associated changes. Temporal comparisons, as described by Cridland and Fitzgerald (2000) provide the most accurate of reporting for vegetation cover levels using NDVI.

Even though developed as a global monitoring satellite, the NOAA dataset, which provides the majority of NDVI data brings with it errors relating to data quality and sensor limitations.

Studies undertaken in other rangeland areas, Kalahari, found that NDVI data also collected changes in background reflectance characteristics, rather than actual changes in green vegetation cover (Ringrose et al. 1989). The results indicated that for this region, soil reflectances had dominated the NDVI values and were not indicative of greenness values.

Due to the low statue and patchy nature of rangeland vegetation, it is important to investigate and use indices, which compensate for high soil reflectance. Studies undertaken have found that in low vegetation areas, errors in the NDVI values were due to reflectance of the exposed soil. Ringrose et al. (1989) and other studies Ringrose et al. (1994) have demonstrated that traditional vegetation indices, including NDVI, don’t provide sufficient spectral separation for semi arid and sparsely vegetated regions, as the NIR reflectance recorded is usually higher from the soil than the vegetation cover.

The development and progress made with correcting NDVI for soil and atmospheric influences have resulted in optimised vegetation indexes for vegetation monitoring. These are based upon the MODIS satellite and able to provide greenness information at an increased temporal and spatial scale (compared to current global monitoring programs).

The Enhanced Vegetation Index (EVI) is an optimised version of NDVI to isolate green or photo-synthetically active vegetation from the spatially and temporally variable pixels of the MODIS satellite data.

Initial studies of MODIS NDVI and EVI have shown both are effective to detect seasonal vegetation variations and land cover changes and assessing spatial and temporal changes in vegetation biomass and condition (Huete et al. 2002).

Australian Rangeland Indices

As described, rangelands are generally sparsely vegetated landscapes composed largely of dry or non green vegetation. Traditional indexes as discussed rely upon green vegetation to detect vegetation cover levels. These are not applicable to Australian rangeland conditions as vegetation is dry for the majority of the time and when green, not very green.

Application of NDVI to Australian rangelands found poor correlations with both dry and green vegetation (Pickup et al*.* 1993) and an over estimation of vegetation levels during ephemeral growth pulses after rain events (Graetz and Gentle, 1982).

Rangeland monitoring in the wet dry tropics experience different conditions thus requires a different index. A study undertaken by Ringrose et al (1994) of the relationship between Landsat data and vegetation across a north south gradient in the NT, suggested that Northern Australia needs to be monitored using different indices.

Within the NT, Landscape Cover Change Analysis (LCCA) method has been developed and uses statistical summaries for long term Landsat data for highlighting areas with different vegetation cover levels (Wallace et al. 1994; Karfs et al. 2000). This technique is based upon Landsat MSS band 2/Landsat TM band 3, as this band was found to discriminate between vegetation and bare soil well in north Australia (Karfs, 2002).

The study undertaken highlighted the complexities involved when monitoring, working and deriving vegetation cover levels for rangelands within north Australia.

As discussed, the B1 data was able to provide consistent and defined delineation between vegetation condition classes upon black soils.

This is due to dark soil having a lower spectral reflectance, than the light coloured hayed-off vegetation. As poor condition sites begin to lose the annual growth coverage and the soil is exposed, the spectral reflectance decreases, reflecting the soil. Conversely, good condition sites made up of perennial grasses shed less vegetation cover as the dry season persists, so the reflectance values are those of the remaining vegetation, which has a higher value.

The use of the visible red band data (B1 MODIS, B2 Landsat MSS and B3 Landsat TM) is the basis for the NT government satellite monitoring program of the pastorally significant basaltic grassland plains. This has proved effective and efficient in providing information upon land condition within the VRD (Karfs et al, 2000, Wallace 1998, Ludwig et al 2000, Wallace 1994). The study has highlighted that MODIS data is able to repeat these results consistently for basaltic plains and would be able to be integrated within the current monitoring program.

Red soil land types are complex and relatively heterogeneous, with varying land form and cover. They are heavily treed and have varying vegetation types, ranging from species that hay-off to light coloured senescent vegetation to spinafex dominated vegetation that remains green year round. This varying vegetation cover coupled with the light soil background poses problems for a clear interpretation of satellite imagery. As highlighted by Ringrose et al 1989 the reduced density or coverage of green ground vegetation cover causes NIR or B2 reflectance to be made up of and dominated by soil, thus providing inaccurate cover level readings.

An issue and potential limitation of the project was the required size of field sites. Due to a sequence of above average seasons, 1999 to 2003 (Bureau Meteorology) resulting in areas with high growth and good cover levels, and the size of the MODIS data at 250m, field sites had to have a minimum size of 500m x 500m on the ground to provide adequate coverage by the MODIS data.

The size restrictions resulted in sites selected being either extremely poor or very low condition to sites with good condition to provide near as possible homogeneous cover of the site.

Another issue related to the scale of the MODIS data was the applicability of collected ground data to the increased satellite pixel size.

The majority of ground data used was based upon an area totalling one hectare in size (100m x 100m). The spatial resolution of a MODIS pixel is 250m, which is significantly greater than the ground data. Tier 2 monitoring sites were setup as a representative site within the areas to allow for mis-registration of imagery and reducing of bias in ground data.

To scale the ground data up, local knowledge, history and ancillary data available for the region were used to ensure the sites selected were as representative as possible.

The applicability of B1 and B2 MODIS data for monitoring changes upon basaltic land types was demonstrated through this project. Increased pixel size and frequency of acquisition provided effective information for the detection of changes upon the landscape. Information could be provided to report upon within the season variation, from month to month, as well as between seasons, annual reporting.

Conclusion and Recommendations

The management of rangelands is very complex, requiring an understanding of processes occurring and an appreciation of the landscape as a whole. Remote sensing technologies, with repeatability and objective data collection, provide a tool to gather information and further increase the understanding of these landscapes.

The study undertaken provided initial application for MODIS data for the monitoring of rangelands within north Australia. It assessed the capabilities of B1 and B2 data for integration with the current Landsat monitoring program.

B1 and B2 data are both highly effective and efficient in detecting differences between condition classes upon the black soil plains of the Victoria River Downs property. They are able to detect differences both within the season, from month to month of the dry season and also provide information on the condition between years.

The effectiveness of 250m MODIS data to track changes within the basaltic landscapes was demonstrated. The information and results attained for basaltic soils were consistent with those from the existing Landsat data.

The project also highlighted the need for further work and assessment of landscapes composed of red soil and red soil derivatives as neither bands, B1 and B2, were found conclusive in the application to rangeland condition monitoring upon red soils.

Recommendations

Further advancement and application of MODIS data would include:

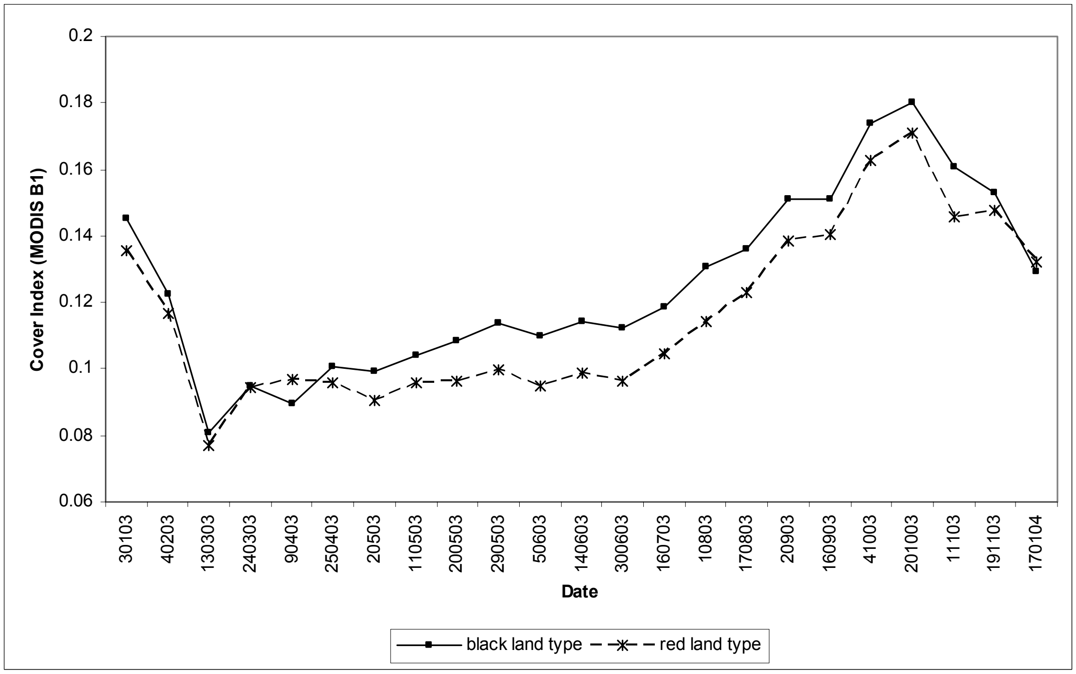
The further investigation of red soil land types and the correlations that be drawn between the MODIS data and light coloured soil land types.

An extrapolation of MODIS data to other regions across the NT where darker soil land types exist. The Barkly pastoral district has extensive areas of dark coloured soils dominated by grass cover that is used primarily by the pastoral industry. MODIS data would provide timely information upon the cover levels and thus land condition of the Barkly tableland.

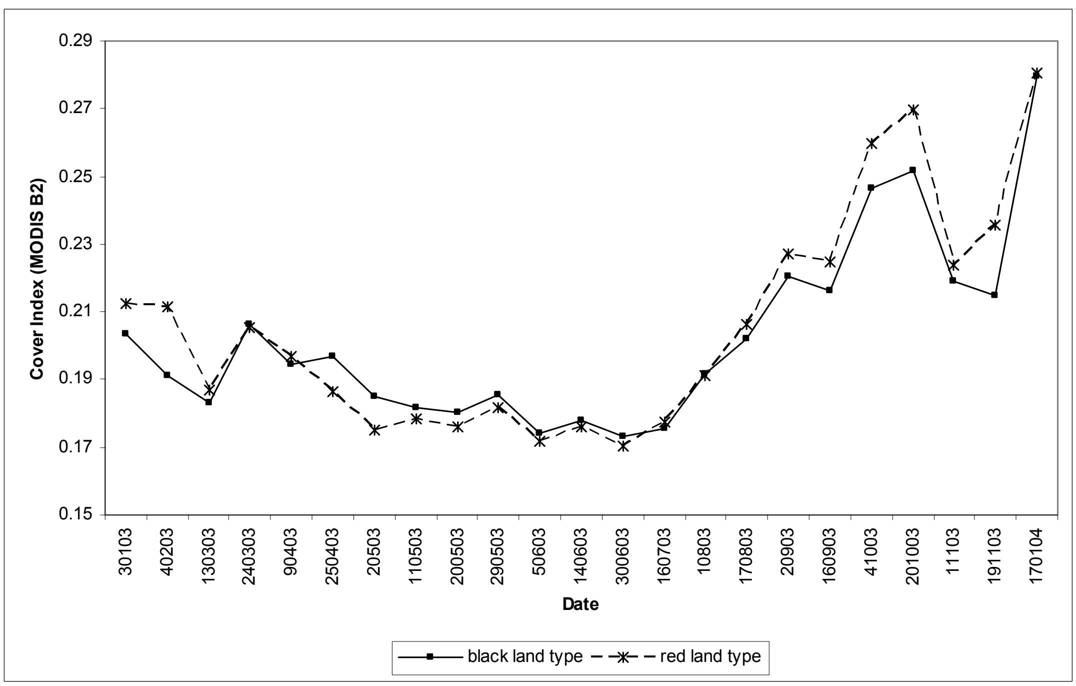
Apply the new MODIS index, EVI to areas of known condition with ground sites to verify the effectiveness upon Australian rangeland areas.

Investigate calibrating the MODIS data to see if any differences or improved results are attained for specific areas in Australian rangelands.

Appendix 1 – The soil effect.

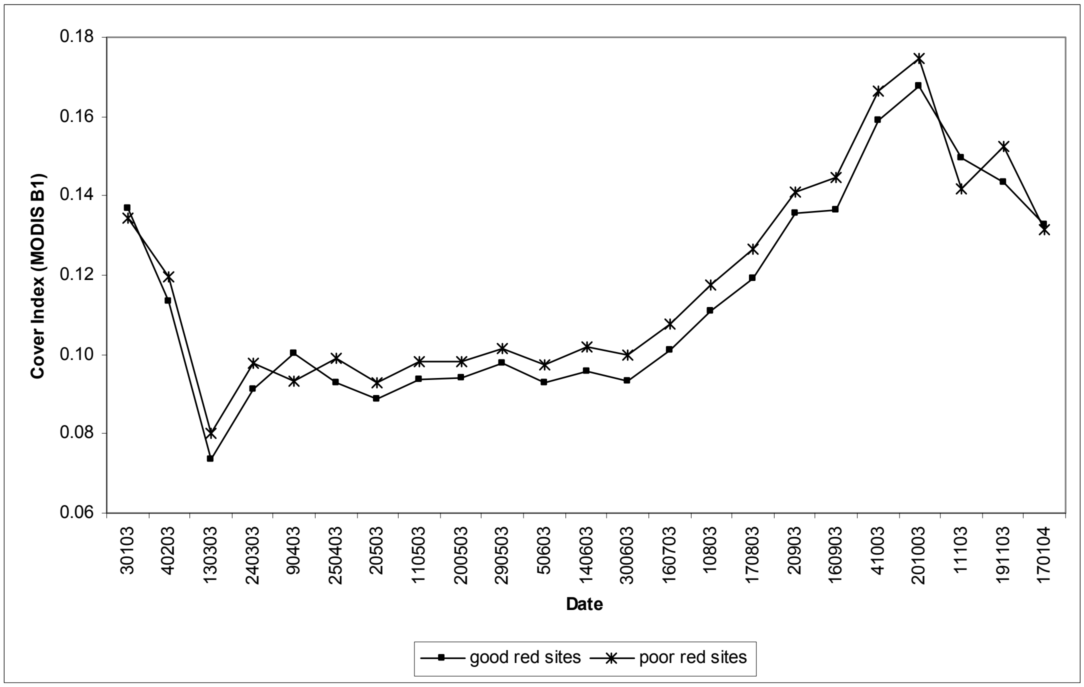


Appendix 1a. Time trace of red and black land type reflectance values from B1 MODIS data. Discrimination between the two land types is apparent for most of the year, especially in the dry season, where the greatest separation is apparent.

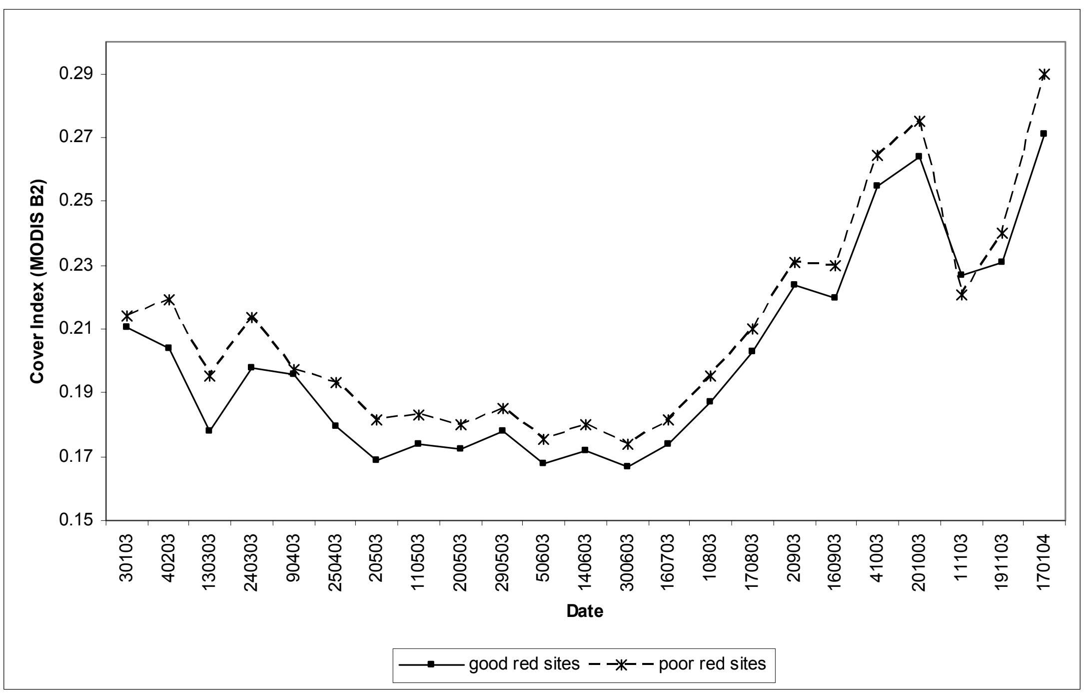


Appendix 1b. Time trace of red and black land type reflectance values from B2 MODIS data. Differences between the two land types were not significant or detectable.

Appendix 2 – The soil/condition effect – Red soil.

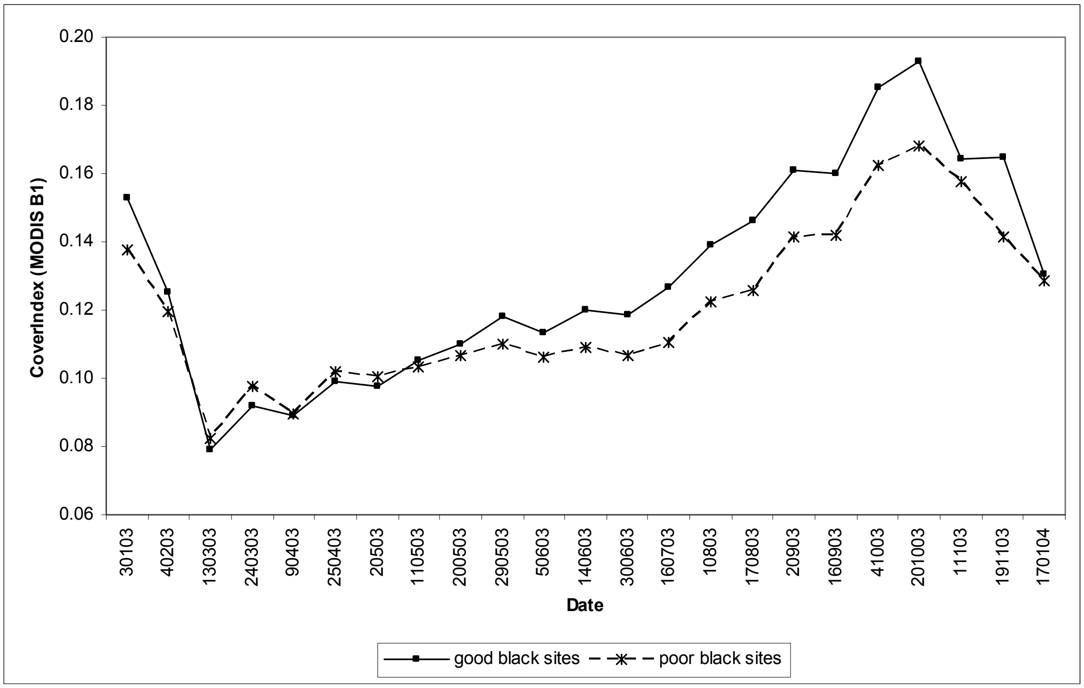


Appendix 2a. Time trace of red soil condition class reflectance values from B1 MODIS data. No significant differences were able to be detected between the good and poor condition classes using B1 MODIS data.

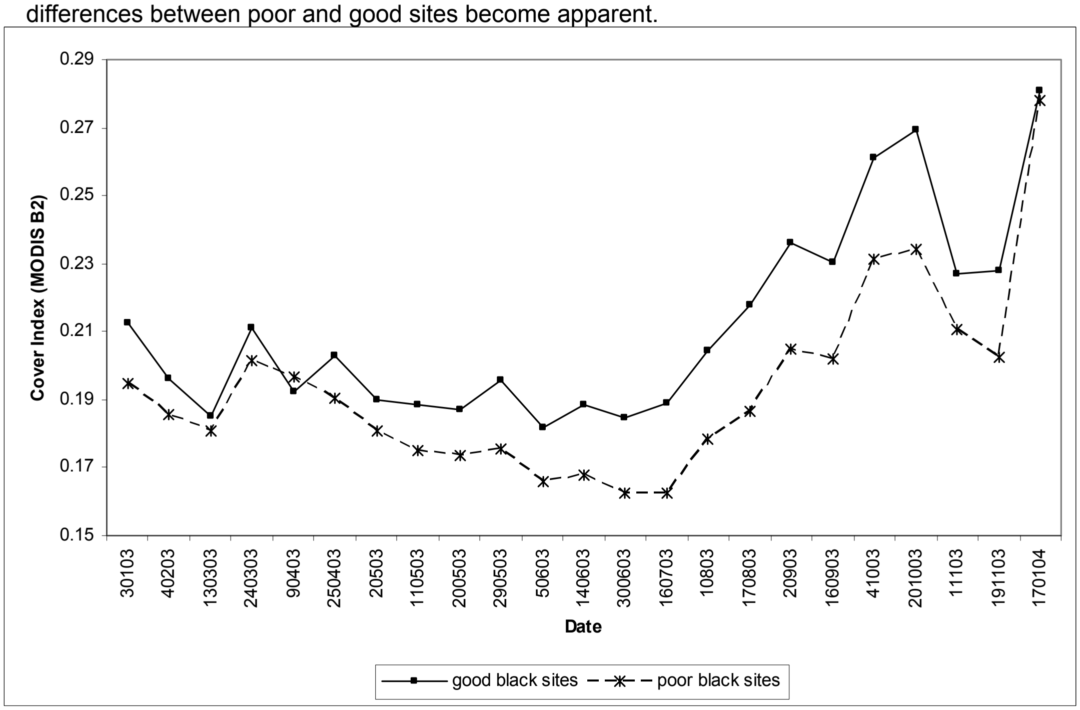


Appendix 2b. Time trace of red soil condition class reflectance values from B2 MODIS data. No significant differences were able to be detected between the good and poor condition classes using B2 MODIS data for use in rangeland condition reporting.

Appendix 3 - The soil/condition effect – Black soil.



Appendix 3a. Time trace of the black soil land type with poor and good sites for B1 MODIS data. Discrimination between good and poor sites during the wet season is difficult due to high levels of green cover. As the dry season prevails and vegetation cover loses moisture content, differences between poor and good sites become apparent.



Appendix 3b. Time trace of black soil land type with poor and good sites for B2 MODIS data. Discrimination between good and poor sites during the wet season is difficult die to high levels of green cover. Separation between sites of varying condition is detectable as vegetation cover begins to hay off.

References

Australian Greenhouse Office (2002) *National Greenhouse Inventory – Analysis of Trends and Greenhouse Indicators 1990 to 2000.* Australian Greenhouse Office, Commonwealth of Australia.

Bastin, G.N., Pickup, G., Chewings, V.H, and Pearce, G. (1993) *Land degradation assessment in central Australia using a grazing gradient method*. The Range land Journal. 15(2) 190-216

Cridland, S., Burnside,D., and Smith, R. (1995). *The NDVI – Use in Rangeland Management.* Fifth International Rangelands Congress, Salt Lake City, Utah, USA. P105.

Cridland, S., and Fitzgerald, N (2000). *Incidence of Extreme Climatic Events*. National Land and Water Resources Audit, Project Reference DET4.

Cridland, S.W and Fitzgerald, N.J (2001) *Apparent Stability in the Rangelands using NDVI-derived Indicators.* IEEE Conference Proceedings – Sydney

Danaher, T., Wedderburn, G. R., Kastanis, L. E. & Carter, J. O. (1998) *The Statewide Landcover and Trees Study (SLATS) - Monitoring land cover change and greenhouse gas emissions in Queensland.* In: Proceedings of the 9th Australasian Remote Sensing and Photogrammetry Conference, 20-24 July 1998, Sydney.

Friedel, M. H., Pickup, G. and Nelson, D. J. (1993). *The interpretation of vegetation change in a spatially and temporally diverse arid Australian landscape*. J. Arid Environments. 24: pp 241-260-80.

Graetz, R. D. (1987). *Satellite remote sensing of Australian rangelands*. Remote Sensing of Environment. 23: pp 313-331.

Graetz, R.D. and Gentle, M.R. (1982). *The relationships between reflectance in Landsat*
wavebands and the composition of an Australian semi-arid shrub rangeland.
Photogrammetric Engineering and Remote Sensing. 48:(11), pp 1721-1730

Graetz, R.D., Carneggie, D.M., Hacker, R., Lendon, C., Wilcox, D.G (1976) *A Qualitative Evaluation of Landsat Imagery of Australian Rangelands.* Australian Rangeland Journal, 1:53-59

Hall, W.B., Bean, J., Beeston, G., Dyer, R., Flavel, R., Richards, R., Tynan, R. and Watson, I. (1999). *Aussie GRASS: Australian grassland and rangeland assessment by spatial simulation*. In: People and Rangelands: Building the Future (Eds D. Eldridge & D. Freudenberger), pp. 854-855. Proc. VI International

Rangeland Congress, Townsville, July 19-23. VI International Rangeland Congress Inc., Townsville, Australia.

Holm, A. (1998*). Theme 4 – Rangeland Monitoring: Guiding Principals and Work Plan*. National Land and Water Resources Audit. http://www.nlwra.gov.au/full/30_themes_and_projects/48_themes/4_rangelands_monitoring/05_work_plan_part_2/work_plan_part_2.html

Huete, A.R., C. Justice, and W. van Leeuwen, (1999). *MODIS Vegetation Index (MOD 13) Algorithm Theoretical Basis Document,* University of Arizona, Tuscon.

Karfs, R., Applegate, R., Fisher, R., Lynch, D., Mullin, D., Novelly, P., Peel, L., Richardson, K., Thomas, P. and Wallace, J., (2000), *Regional land condition and trend assessment in tropical savannas: The Audit Rangeland Implementation Project Final Report*, National Land and Water Resources Audit, Canberra

Ludwig, J.A., Bastin, G.N., Eager, R.W., Karfs, R., Ketner, P., and Pearce, G. (2000) *Monitoring Australian Rangeland sites using landscape function indicators and ground-and remote-based techniques.* Environmental Monitoring and Assessment. 64. Kluwer Academic Publishers, Netherlands. 167-178

Ludwig, J., Tongway, D., Freudenberger, D., Noble, J. and Hodgkinson, K. (1997). *Landscape ecology, function and management: principles from Australia's rangelands*. CSIRO Publishing, Melbourne, Victoria.

McLeod, P.J. and VanCuylenburg, H. R. M. (In prep.). *Land Resources of the Victoria River District*. Resource Capability Assessment Branch, Department of Infrastructure Planning and Environment, NT.

McIvor, J.G., Ash, A.J., and Cook, G.D. (1995) *Land Condition in the tropical pasture lands1. Effects on herbage production.* Rangeland Journal, 17(1): 69-85

Reeves, M.C., Winslow, J.C., Running, S.W., (2001) *Mapping Weekly Rangeland Vegetation Productivity Using MODIS Algorithms.* Journal Range Management, 54:A90-A105.

Ringrose, S., Matheson, W., Mogotsi, B and Tempest, F (1989) *The darkening effect in drought affected savanna woodland environments relative to soil reflectance in Landsat and SPOT wavebands*. Remote Sensing of Environment. 30:1-19.

Ringrose, S., Matheson, W., Matalala, C.J.S.S., O'Neill, T., and Werner, P.A. (1994) *Vegetation spectral reflectance along a north-south vegetation gradient in northern Australia.* Journal of Biogeography. 21:33-47.

Pickup, G., Bastin, G.N. and Chewings, V.H., (2000), *Measuring rangeland vegetation with high resolution airborne videography in the blue-near infrared spectral region.* International Journal of Remote Sensing, 21, 339-351.

Pickup, G., Bastin, G.N. and Chewings, V.H. (1998). *Identifying trends in land degradation in non-equilibrium rangelands*. Journal of Applied Ecology, 35, 365-377.

Stewart, G.A., Perry, R.A., Paterson, S.J., Traves, D.M., Slatyer, R.O., Dunn, P.R., Jones, P.J. and Sleeman, J.R. (1970). *Lands of the Ord-Victoria Area, Western Australia and Northern Territory.* CSIRO Land Research Series No.28. Melbourne.

Strabala, K.I, Gumley, L.E, Rink, T, Huang, H-L and Dengel, R (2002) *MODIS direct broadcast products and applications.* Conference paper SPIE. Remote Sensing of the Atmosphere, October 2002.

Tongway, D. and Hindley, N. (1995), *Manual for Assessment of Soil Condition of Tropical Grasslands,* CSIRO, Division of Wildlife and Ecology, Canberra, Australia.

Tongway, D. J. and Ludwig, J.A. (1997). *'The Nature of Landscape Dysfunction in Rangelands'*. In: Landscape ecology, function and management: principles from Australia's rangelands. Eds: J. Ludwig, D. Tongway, D. Freudenberger, J. Noble and K. Hodgkinson. CSIRO Publishing, Melbourne, Victoria, pp. 49-63.

Tueller, P.T. (1989) *Remote sensing technology for rangeland management applications.* Journal Range Management 42(6):442-453

Wallace, J.F., Holm, A.McR., Novelly, P. E. and Campbell, N.A. (1994). *Rangeland monitoring and change detection using remote sensing*. National Landcare Program Project 91/W/M5 Final Report. CSIRO Division of Mathematics and Statistics, Agriculture Western Australia.

Wallace, J.F. and Thomas, P.W.E. (1998). *Rangeland monitoring in northern Western Australia using sequences of Landsat imagery.* Report to National Landcare Program Project No. 953024. Agriculture Western Australia, unpublished.

Wylie, B.K., Harrington, J.A.Jr., Prince, S.D., and Denda, I. (1992) *Satellite and ground based pasture production assessment in Niger:1986-1988*. International Journal Remote Sensing, 12(6):1281-1300

Zhan, X., Sohlberg, R.A., Townshend, J.R.G., DiMiceli, C., Carroll, M.L., Eastman, J.C., Hansen, M.C, DeFries, R.S (2002) *Detection of land cover changes using MODIS 250m data*. Remote Sensing of Environment 83:336-350.