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Bureau of Rural Sciences

Department of Environment and Resource Management

Ground cover management practices in cropping and improved pasture grazing systems: ground cover monitoring using remote sensing

FINAL REPORT

Toward Q2 Tomorrow's Queensland
Queensland Government

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Contents

List of figures

List of tables

1. Introduction

1.1. Ground cover and erosion

Ground cover is the proportion of the underlying soil material that is covered by the vegetative ground layer or superficial rock material. The vegetative ground layer consists of living or dead plant material and includes live grasses and forbs, leaves and branches and cryptogams such as mosses and lichens. Ground cover changes in response to climate, vegetation dynamics and land management. The quantity of ground cover affects water infiltration, runoff and erosion. It is also linked to the key land condition indicators of pasture production and biodiversity. Estimates of ground cover and changes to the quantities and spatial arrangement of ground cover over time provide land managers, policy-makers and scientists with valuable information. This helps inform decisions in relation to soil erosion, soil carbon, water quality, pasture production, land condition, climate change, fire and regional management targets. For the purposes of this report, we refer to ground cover as the vegetative ground cover component, which is detectable through the use of satellite imagery.

A recent report by Leys et al. (2009) identified ground cover as a key indicator of land management practices. Importantly, ground cover can be used to infer and monitor wind and water erosion risk. The report noted that many catchment action plans of regional Natural Resource Management (NRM) bodies are using ground cover as a surrogate for erosion risk. However, at both the national and regional levels, there remains a lack of comprehensive, consistent ground cover data at a temporal and spatial scale adequate for monitoring and assessing environmental targets related to soil erosion and land management.

1.2. Remote sensing of ground cover

Ground cover estimates, derived from remotely sensed imagery are important land condition indicators and become increasingly useful when a time-series of ground cover information is available. A number of techniques have been developed for estimating ground cover quantities and crop residues using remotely sensed imagery. For example, Daughtry (2001) and Daughtry et al. (2005, 2006) used the spectral libraries of crop residues and crop types, combined with multispectral (Landsat TM) and hyperspectral imagery (AVIRIS, Hyperion) to compare spectral residue and soil indices, including the cellulose absorption index (CAI), to assess crop residue levels and types in the United States. In Australia, a comprehensive review of techniques was undertaken by Leys et al. (2009) (refer to appendix 3 in their report). In their report, and following an expert workshop, they summarised four ground cover estimation techniques that may be most suitable for erosion modelling. These techniques included:

i. Annual estimates of woody fractional cover using the Queensland statewide landcover and trees study (SLATS) method based on Landsat TM data (Danaher et al., 1998).
ii. Monthly bare ground index (BGI) methods for Landsat (Scarth et al., 2006) and MODIS (Milne et al., 2007).
iii. Monthly fractional cover using the CSIRO MODIS non-woody fractional cover method (Guerschman et al., 2009).
iv. Monthly fractional cover using the CSIRO AVHRR data archive (Donohue et al., 2008).

There are, in fact, five products listed above as ii. contains both Landsat and MODIS scale cover products. Each of these products derives slightly different estimates of cover due to what they measure and the temporal and spatial scale at which they operate. The original estimates of woody fractional cover (Danaher et al., 1998) undertaken by the Queensland Remote Sensing Centre (QRSC) are presently generated as annual estimates of woody Foliage Projective Cover (FPC) following the methods described by Danaher et al. (2004). The BGI methods of Scarth et al. (2006) are presently annual estimates of ground cover as derived from a Ground Cover Index (GCI) using Landsat imagery. The GCI is calibrated using ground-based measurements of ground cover fractions, primarily from rangeland systems. The BGI methods of Milne et al. (2007) use the MODIS 16-day and 8-day composites at 1km and 500m resolution respectively, and were calibrated using the Landsat GCI product. The products developed by Guerschman et al. (2009) use field-derived spectral libraries of fractional ground cover in Australian tropical savannas. The spectral libraries in this method were compiled using EO-1 Hyperion hyperspectral imagery to explore the spectral response space to develop fractional cover endmembers. These were used along with the Normalised Difference Vegetation Index (NDVI) and the CAI (Cellulose Absorption Index) in a linear mixture approach. The approach was then applied to daily MODIS imagery at 500m resolution (coincident with the Hyperion imagery) and then to six years of the MODIS 16-day composite imagery at 1km resolution to resolve quantitative estimates of photosynthetic vegetation (PV), non-photosynthetic vegetation (NPV) and bare soil for ~2 million km2 of the Australian tropical savanna zone. More recently, this approach has been applied to the MODIS 8-day composite at 500m resolution for the entire Australian continent. The monthly fractional cover estimates produced by Donohue et al. (2008) are a product of a relative reflectance calibration technique that assumes that the position of the vegetation cover triangle is invariant in reflectance space. This technique has been applied nationally to AVHRR data at approximately 1km resolution.

Of the ground cover and crop residue measurement techniques described above, none of the methods developed have been designed or calibrated for the range of intensive agricultural systems (i.e. cropping and improved pasture) in Australia. Some studies have been undertaken using remote sensing time-series techniques to monitor Australian crop types and seasonal patterns in cropping rotations (e.g. Potgeiter et al., 2007; Pringle et al., 2008). However, these studies do not provide estimates of ground cover and crop residue levels at different stages of the cropping cycle and have used imagery (e.g. MODIS) that is at a resolution too coarse to accurately monitor many cropping systems in Australia.

1.3. Field-based measurements of ground cover for calibration of remote sensing

Field-based ground cover measurements for calibration of remote sensing data have a number of experimental and logistical considerations. They must be designed to be representative of the natural complexity and spatial and temporal variability of the ground cover in the environment to be monitored. The selected method/s need to be applicable to multiple regions where crop, pasture and soil types and management practices differ. The methods used must also consider the spectral, spatial and temporal characteristics of the imagery to be calibrated for ground cover estimation. The methods must also be easily and consistently applied across different regions in an objective, quantitative and cost-effective way.

Many methods have been used or recommended for the measurement of ground cover in the field (e.g. Daughtry et al., 2006; Victorian Department of Primary Industries, 2005; also see Booth et al., 2006 for a comprehensive review). Only some of these methods are suitable for calibration of ground cover estimates using satellite imagery and none have been tested in the range of environments and agricultural systems that occur in Australia. Scarth et al. (2006) described and used a star-shaped sample with 3x100m intersecting transects at angles of 0^0, 60^0 and 120^0 which represent an approximate 3x3 pixel area (~1ha) for Landsat data. This approach has been successfully applied in rangeland systems and improved pastures to calibrate Landsat imagery and map complex natural grasslands, pastures and improved pastures with acceptable accuracies. To date, this technique has not been applied in intensive agricultural systems. Daughtry et al. (2006) measured crop residue using a cross-shaped 15.2m line-point transect with 100 evenly spaced markers. Guerschman et al. (2009) did not quantitatively measure ground cover in the field; they collected field spectra of ground cover fractions and then related these to hyperspectral imagery for endmember extraction. Daughtry (2001) and Daughtry et al. (2005, 2006) also collected laboratory and field-based spectra to calibrate hyperspectral imagery.

The star-shaped transect approach as outlined in Scarth et al. (2006), which is designed to sample complex rangeland systems, may not be feasible in these systems as the method is time and labour intensive and can potentially inherit a sampling bias in monoculture systems with defined growth and sowing/harvest characteristics (Figure 1). Alternative sample designs might be more effective and consider the range of geometries of the crop management practices and the variability in the plant structure at different stages of the crop cycle.

(a) (b)

Figure 1 Examples of (a) wheat stubble and (b) sorghum stubble (double-skip row) near Goondiwindi, late dry season, May 2009. Photos M. Schmidt.

1.4. Objectives

To date, limited research has been undertaken to compare any of the ground cover measurement techniques developed in Australia, or to assess their accuracy and utility for monitoring ground cover quantities in intensive agricultural areas. A recommendation from Leys et al. (2009) and the related national workshop was for research to be undertaken that compared existing methods for accuracy and functionality.

The objective of this project is to undertake a pilot study to investigate and compare some of the satellite-based ground cover time-series products identified by Leys et al. (2009) for accuracy, functionality and utility in intensive agricultural systems. The spatial, spectral and temporal effects of the satellite imagery are discussed, considering the dynamic aspects of land management practices occurring under cropping and modified pasture land uses. The long-term goal of this project is to establish a network of national reference sites to calibrate and validate ground cover quantities estimated from satellite imagery. Field sampling methods for collection of calibration data are trialled and discussed. The ground cover information will be used to monitor land management practices and their effects on soil erosion and landscape condition across the continent. Recommendations are provided on the basis of the findings of this pilot study and the long-term objectives for national ground cover monitoring.

2. Study areas

For this pilot study, two cropping sites in the Fitzroy basin near Emerald were selected. A further three sites near Charters Towers in the Burdekin catchment were chosen for the improved pasture examples (Figure 2). The Charters Towers area was chosen because the DERM image archive contains up to 20 Landsat images per year for this region, permitting more detailed investigation of seasonal patterns in the time-series. The DERM image archive generally only contains 1 to 2 images per year for the other parts of Queensland. An additional study area near Goondiwindi in southern Queensland was included in this project to trial and assess calibration site methods in cropping areas. This study area was part of a larger study assessing crop yields in relation to surface and subsurface soil parameters (Dang et al., 2009). A further assessment of the GCI was also undertaken in the Keilambete pasture trial area in central Queensland (refer to section 4.2.2).

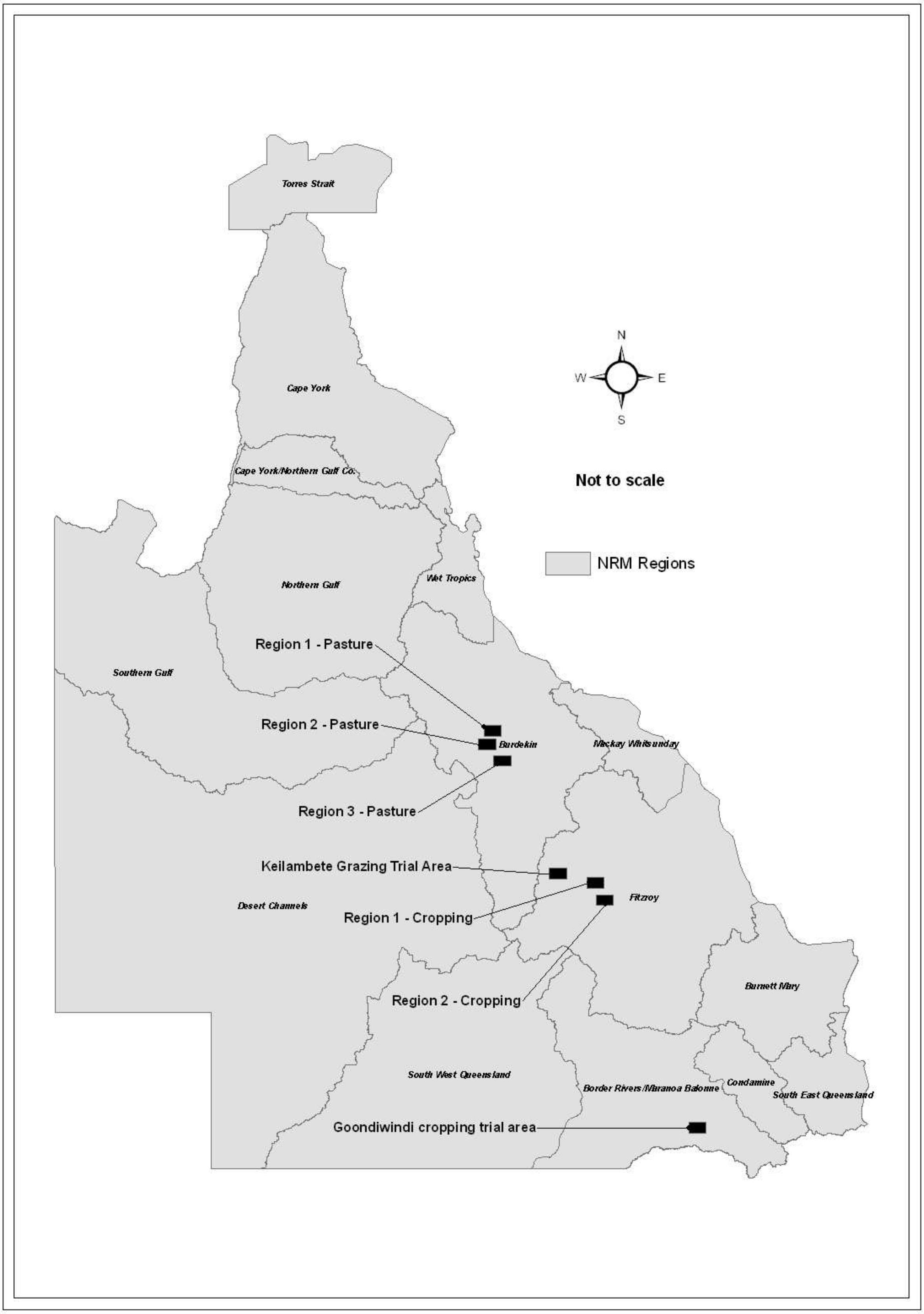

Figure 2 Location of the study sites used in this report.

3. Data

3.1. Field data

Pringle et al. (2008) collated information on agricultural land use and management practices from eighteen land managers across the major cropping areas in the Fitzroy Basin. Information was obtained from the land managers for the period February 2000 to September 2007. The information included:

i. crop type
ii. sowing and harvest dates
iii. inter-crop management (e.g. minimum or zero tillage)

This information formed the basis of the assessment of ground cover products in this pilot study.

3.2. Ground Cover Products

3.2.1. Landsat Ground Cover Index (GCI)

A time-series of medium resolution satellite imagery (30m spatial resolution) from the Landsat program was identified to deliver detailed spatial information content for the agricultural ground cover mapping. Landsat 5 TM (Thematic Mapper) and Landsat 7 ETM+ (Enhanced Thematic Mapper) images from the Queensland Department of Environment and Resource Management's (DERM) archive were geometrically and radiometrically corrected (Armston el al, 2002; de Vries, 2007). The Landsat imagery used in this pilot study was historically purchased at the end of the local dry season as part of the Statewide Landcover And Tree Study (SLATS) program (1988 – 2009).

Ground Cover Index (GCI) data of this time-series were calculated following Scarth et al. (2006). The GCI describes the percentage of plant material (dead or alive) that is covering underlying soil or rock material. GCI data are only calculated for areas with a low woody vegetation component (i.e. less than 15% foliage projective cover). The GCI estimates ground cover by applying a known statistical relationship between measurements of cover made in the field, and measurements, made by satellite sensors, of the light reflected from the same field locations, at close to the same time. Ground cover data from more than 550 field sites, representing the variety of land types throughout Queensland, have been related to corresponding points of satellite data to provide reliable estimates of ground cover across different soil types and different vegetation communities.

The GCI was originally developed as a Bare Ground Index (BGI). The GCI has a direct relationship to the BGI as follows:

GCI (%) = 100 – BGI (%)

3.2.2. MODIS GCI

Milne et al. (2007) used MODIS 500m 8-day composite images to generate GCI data from early 2000 to present. The method is based on an up-scaling of the validated 30m spatial resolution Landsat GCI data with 500m MODIS imagery.

3.2.3. MODIS fractional cover estimate

Guerschman et al. (2009) also used the MODIS 500m 8-day composite images to generate 16-day composites and to derive a fractional cover product based on green (photosynthetically active) vegetation, non-green (non-photosynthetically active) vegetation and bare soil fractions. The cover measurements are based on hyperspectral imagery, validated in the Northern Territory. They also applied a different compositing method to initially smooth the data (see Guerschman et al., 2009 for more details).

3.2.4. MODIS FPAR

MODIS MOD15 Fraction of Photosynthetically Active Radiation absorbed by vegetation (FPAR) Collection 4 data were processed as described in Schoettker et al. (2008). This data has a spatial resolution of approximately $1km^2$. It was found that the agricultural sites under investigation in this pilot study were too small to be detected by a MODIS 1km pixel resolution. This resulted in scale difficulties and ambiguous land surface components as many land cover types were not distinguishable at the MODIS FPAR $1km^2$ scale. Further analysis and investigation of this product was therefore not undertaken.

3.2.5. Rainfall data

Rainfall data was obtained to compare observed patterns in the satellite image ground cover products with seasonal variations in rainfall patterns. A database of daily climate data was accessed to calculate and acquire monthly point-drill rainfall data for each of the study sites. This information was downloaded from http://www.longpaddock.qld.gov.au/silo/.

4. Methods

4.1. Comparison of ground cover products

Spatially homogeneous areas were identified for the comparison of the different time-series data. These homogeneous areas are easily identified at the resolution of a Landsat (30m) pixel, but can be difficult to define at the resolution of a MODIS pixel (500m and 1000m). In the cropping areas with available field information, only two fields could be identified that had an area in the order of one 500m MODIS pixel. However, intrinsic to satellite data is that the spatial location of the off-NADIR pixels contain spatial ambiguity (Wolfe et al, 1999). For that reason, a common recommendation is to use a spatial average value of pixel representation e.g. a 3x3 pixel window.

Due to the limited availability of adequate crop or field sizes, an assumption was made that the location of a single MODIS pixel will coincide exactly with the same area covered by Landsat. An average value of a 500m x 500m area is therefore reported for the Landsat data time-series.

Data exploration plots of the satellite time-series data were generated (see Figure 5 for example), where: the black line represents the Landsat GCI; the red line represents the MODIS GCI; and the remaining brown, green and purple lines represent the MODIS BGI (bare ground index), NPV (Non Photosynthetic Vegetation) and PV (Photosynthetic Vegetation) cover components, respectively (as described by Guerschman et al., 2009).

In a final step, the data was scaled to have the same units and summarised as ground cover data, such that the two cover components of Guerschman et al. (2009) sum to form an index that approximates total cover, i.e. NPV+PV.

4.2. Independent validation of the Landsat GCI

4.2.1. AussieGRASS

The AussieGRASS model (Carter et al., 2000) estimates ground cover from simulated pasture biomass on a daily basis at a resolution of 0.05 degrees. Data from the Landsat GCI product was up-scaled to the AussieGRASS 0.05 degree grid by removing pixels with significant tree coverage or on scene edges. This up-scaling approach enabled the comparison of identical areas on the date of satellite image acquisition.

There had been little direct calibration of ground cover in AussieGRASS therefore a subset of the data (1991 - 2002) was used to recalibrate a single parameter for about one-third of the pasture communities in Queensland to the mean cover derived using the Landsat GCI for the 1991-2002 period (Scarth et al, 2006).

In a final analysis, Landsat GCI data for the period 1988-2005 was used to establish annual means for the entire non-wooded areas covered by Landsat scenes (including most of Queensland and small areas of NT, SA and NSW) and compared to the AussieGRASS model.

4.2.2. Grazing Trial area in Keilambete

An independent validation of the Landsat GCI was performed by Cameron Dougall from the Queensland Department of Environment and Resource Management (DERM) on the basis of a pasture monitoring program as described in Silcock et al. (2005). The single date Landsat GCI was compared with field-based measurements averaged over grazing trial paddocks:

i. cleared of trees
ii. with tree cover (mostly silver-leaved ironbark, *Eucalyptus melanophloia*)

4.3. Sampling design and field data collection for calibration of ground cover estimated from satellite imagery

Trials of different field sample designs were undertaken on two separate field trips to assess the optimal sampling approach for calibration of ground cover estimated from satellite imagery. These trials were undertaken considering all requirements for a consistent national program for calibration of ground cover estimated from satellite imagery (refer to section 1.3).

The star-transect approach, as described in Scarth et al. (2006), has been shown to be an effective, quantitative method for measuring fractional components of ground cover in complex systems, such as native pastures. The field data collected using this approach can be used to calibrate medium-resolution imagery for ground cover estimation. Given that cropping and modified pastures are less complex monoculture systems, it was assumed that the star-transect approach (Scarth et al. 2006) was also an accurate representation of ground cover fractions in these comparatively uniform systems. The method could therefore be used to compare ground cover fractions measured by other sampling designs to select the most appropriate method for application in a national reference/calibration site program.

On the first field trip in May 2009, two sampling designs were trialled in a field with wheat stubble (Figure 3). The sowing rows were 30cm apart, while the stubble diameter within each row was around 10-15cm. For both designs, fractional ground cover measurements were taken at 5cm intervals. The small sampling interval used was an intentional over-sampling to allow for further analysis to help determine optimal sampling intervals for the accurate representation of ground cover at a site. The resulting cover measurements were then sub-sampled to represent and compare different sampling intervals for the fractional ground cover components.

On the second field trip in August 2009, three different sampling designs were trialled in wheat and sorghum stubble, as well as a wheat field which was early in its growth stage. The different sampling designs are shown in Figure 4 and included:

i. star transect as described by Scarth et al. (2006)
ii. representative short transects of 5m and 10m length with variable orientation
iii. diagonal cross-row transects (2x100m)

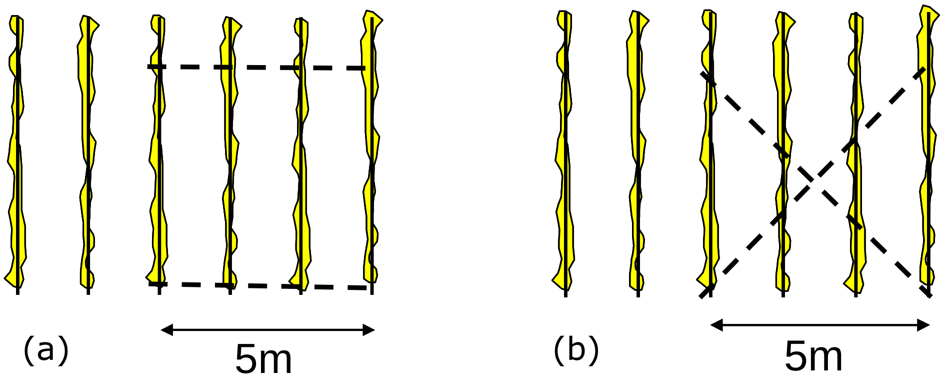

Figure 3 Different sampling design and sampling intervals (a) orthogonal to rows (b) diagonal to rows.

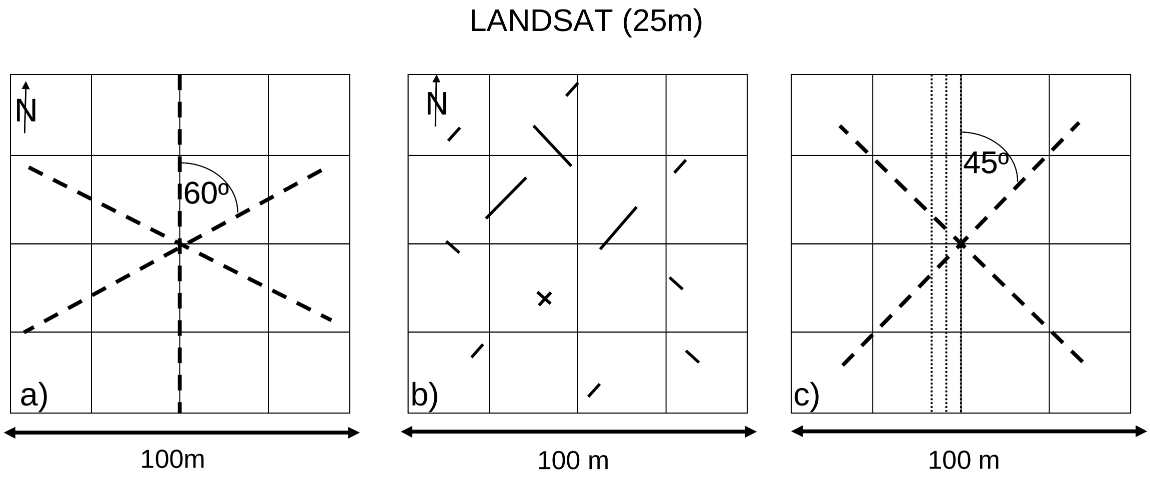

Figure 4 Different sampling designs trialled a) star shaped transect, b) multiple representative 'short' transects and c) diagonal across row transects; grid lines represent Landsat pixel resolution.

For each transect, the following was measured:

i. location and bearing of transects,
ii. fractional ground cover following the methods described by Scarth et al. (2006) at 1m intervals for a) and c) and 10cm intervals for b),
iii. soil type and colour and crop height,
iv. hemispherical photographs (analysis not shown in this report).

As with the first field trip, the small sampling interval used in b) allowed for further analysis of sampling intervals.

5. Results

5.1. Comparison of ground cover products

5.1.1. Region 1 Cropping

Figure 5 and Figure 6 show that the MODIS-based products display a similar fluctuating pattern over time. The Landsat GCI shows a consistently high mean cover estimate for the period 2001 to 2007 and fails to show the seasonal and yearly trends in planting and harvesting. This is due to the limited availability of time-series data and field calibration data in the DERM archive for this study site.

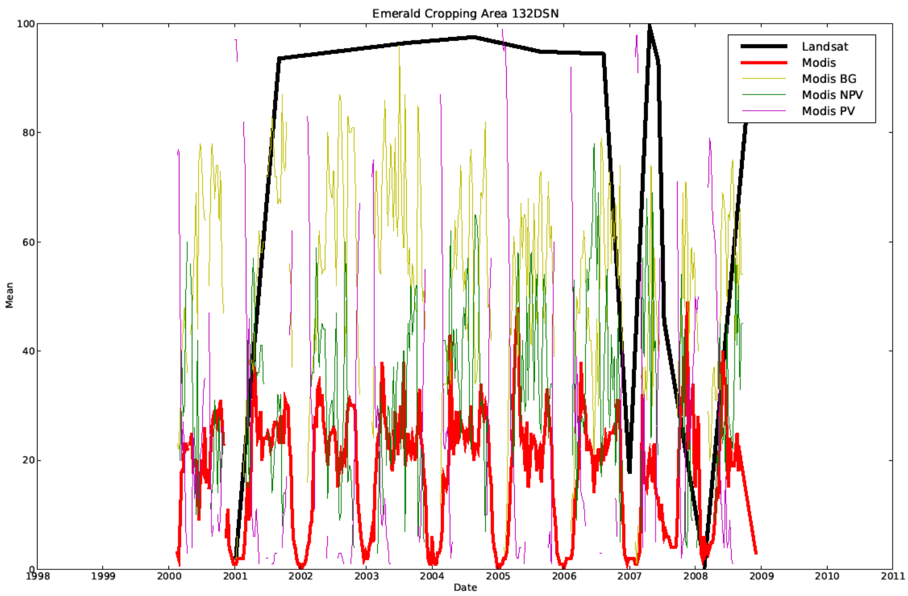

Figure 5 Data exploration plot for Region 1 Cropping near Emerald: the Landsat GCI (Scarth et al., 2006), MODIS BGI (Milne et al., 2007) and the cover fractions as described in Guerschmann et al. (2009). The black line represents the Landsat BGI; the red line represents the MODIS BGI; and the remaining brown, green and purple lines represent the MODIS fractions of bare ground, NPV and PV components, respectively (as described by Guerschman et al., 2009).

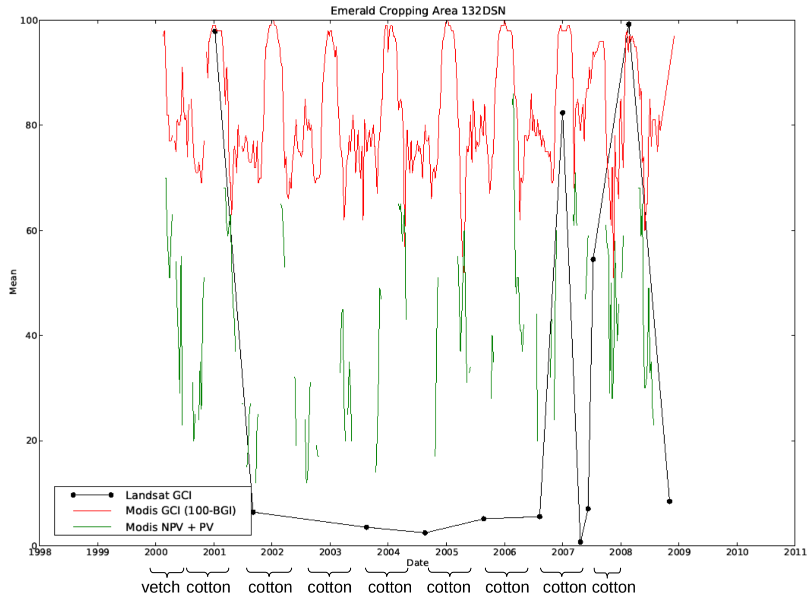

Figure 6 Ground cover data from Landsat GCI (Scarth et al, 2006), MODIS GCI (Milne et al, 2007) and MODIS NPV+PV (Guerschman et al., 2009) including the approximate crop growing times. The time-series gaps in the data produced by Guerschman et al. (2009) are likely due to their rigorous data flagging.

5.1.2. Region 2 Cropping

Figure 7 shows the spatial context of the cropping field from which coincident field and satellite data was available. The size of the field did not allow calculating average GCI values for MODIS resolution in the desired 3x3 pixel location. However as the MODIS pixel is in the centre of the field there is at least one half a MODIS pixel buffer for a potential location error in the MODIS pre-processing. The Landsat GCI values were averaged for the same 500m x 500m area.

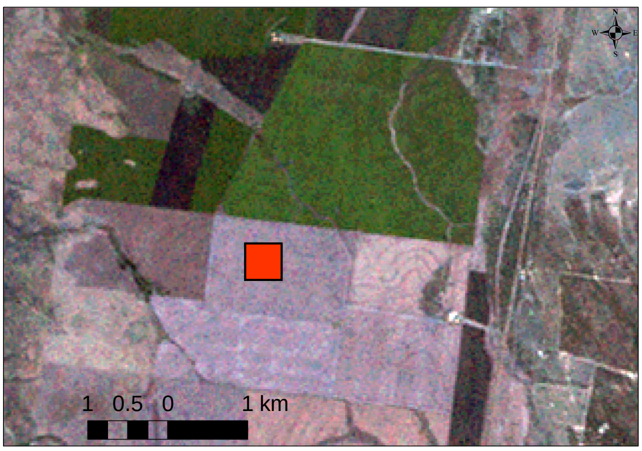

Figure 7 Pixel location (in red) for the 500m MODIS GCI and the Landsat GCI average for Region 2 Cropping. Imagery: Landsat 5 TM true colour composite from July 12, 2007.

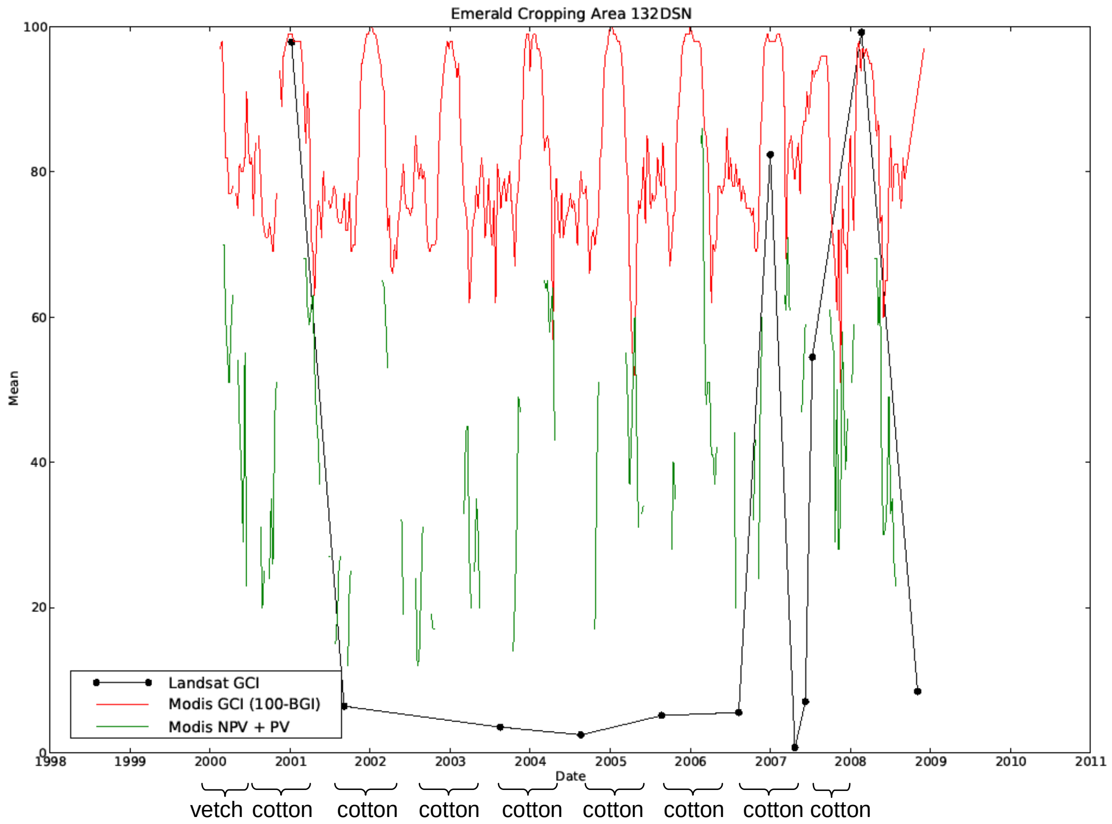

Figure 8 Ground cover data from Landsat GCI (Scarth et al., 2006), MODIS GCI (Milne et al., 2008) and MODIS NPV+PV (Guerschman et al., 2009) including the approximate crop growing times according to land manager information collected indicating crop rotation history.

Figure 5, Figure 6, and Figure 8 for the cropped areas clearly show the problems that exist with gaps in the time-series due to the limited temporal resolution of the Landsat data and a lack of access to the complete Landsat archive. Cropping cycles are seasonal, and the majority of this data is based on one or two late-dry-season images. The time-series therefore misses key planting, growing and harvesting times throughout the cropping cycle. The plots for the MODIS GCI demonstrate that with a higher temporal frequency, estimates of ground cover patterns throughout the cropping cycle can be estimated. However, as mentioned, these estimates suffer due to the spatial resolution of the MODIS imagery.

5.1.3. Region 1 Improved Pasture – homogeneous pasture with no tree cover

Figure 9 shows a data exploration plot for the improved pasture areas over the complete Landsat time-series (from 1986 to 2009). The plot also overlays MODIS data from when the satellite data was first available in 2000. The plot shows a period of consistently high cover between 1993 and 1997.

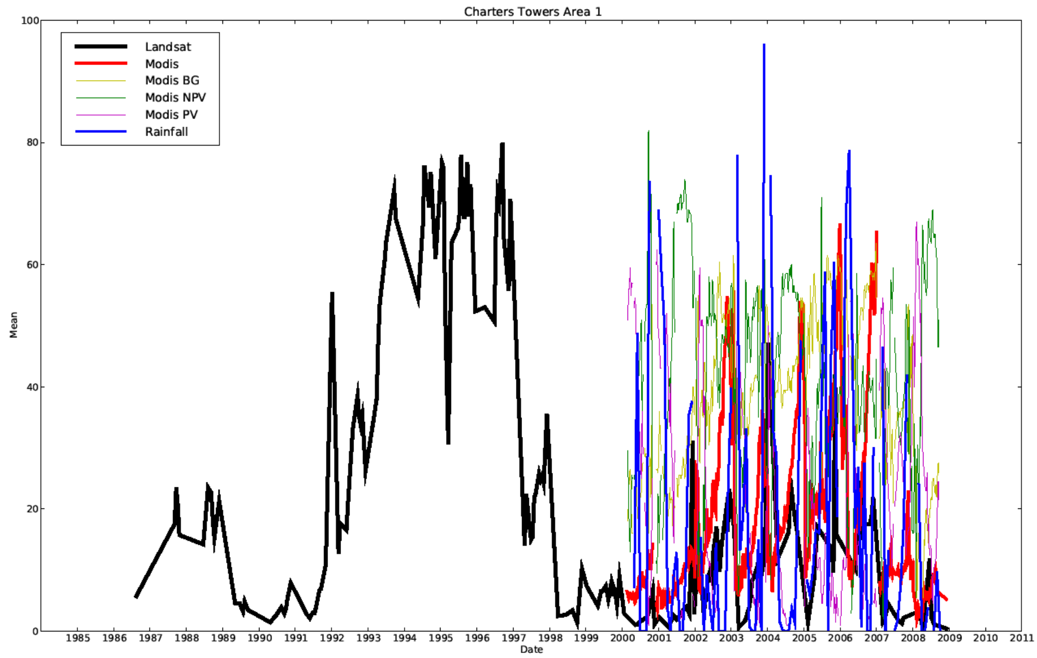

Figure 9 Data exploration plot for Region 1 – Improved pastures near Charters Towers. The black line represents the Landsat BGI; the red line represents the MODIS BGI; and the remaining brown, green and purple lines represent the MODIS fractions of bare ground, NPV and PV components, respectively (as described by Guerschman et al., 2009).

Figure 10 shows the scaled version of the data exploration plots spanning the common observation interval of the Landsat and MODIS time-series data. The Landsat archive was not flagged for cloud coverage. Three outliers of the Landsat time-series could be attributed to cloud contaminated imagery: October 2001; December 2003; and December 2005 (see dotted circles in Figure 10). All ground cover products follow relatively similar trends and patterns of changes in cover levels. However, there are clear differences between the products for the absolute levels of cover estimated. Further work is required to determine which product is nearest to the true cover value. The products also show a general trend related to rainfall patterns where high rainfall generally shows a trend towards high cover, and low rainfall a trend towards low cover. There may be a slight time lag between rainfall events and cover changes, presumably due to pasture growing and curing cycles.

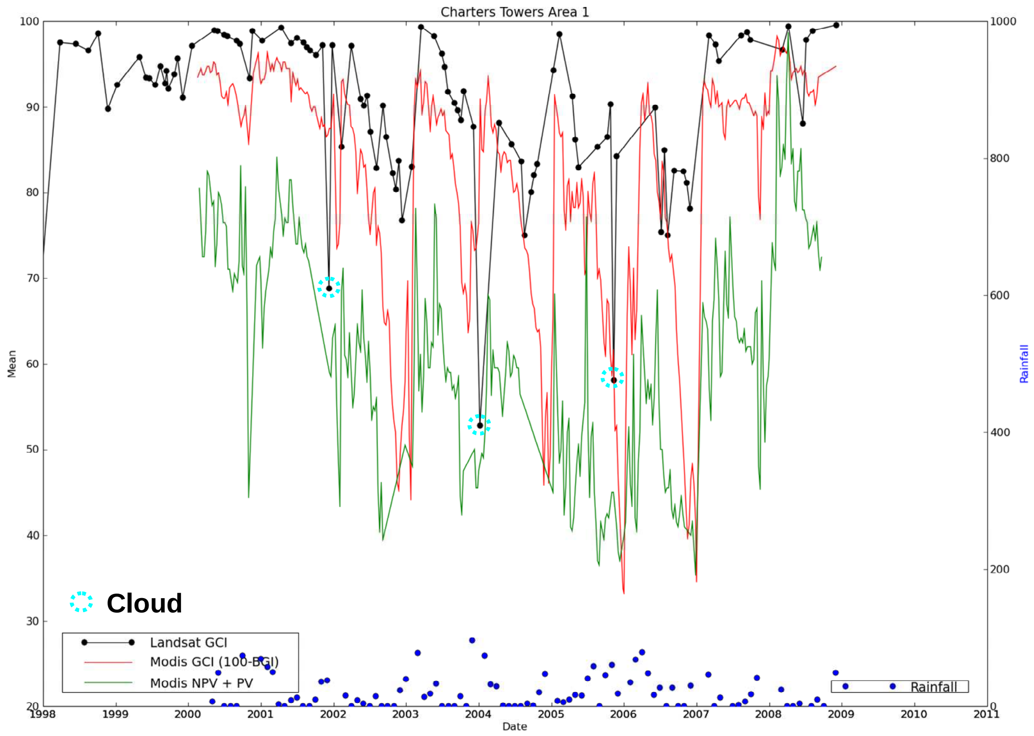

Figure 10 Ground cover data from Landsat GCI (Scarth et al, 2006), MODIS GCI (Milne et al, 2008) and MODIS NPV+PV (Guerschman et al , 2009) including rainfall data, for Region 1 Improved Pasture. Cloud affected images in the Landsat time series are indicated.

5.1.4. Region 2 Improved Pasture – homogeneous pasture with no trees

Figure 11 shows a GCI plot for Region 2 Improved Pasture. The plot shows that for this study site, the Landsat and MODIS GCI are closely following the same trend. The MODIS fractional cover estimate time-series based on Guerschman et al. (2009) also follows the same general pattern, but with a negative bias. As was the case with Region 1 Improved Pasture, there is also a general relationship between rainfall and cover trends through time.

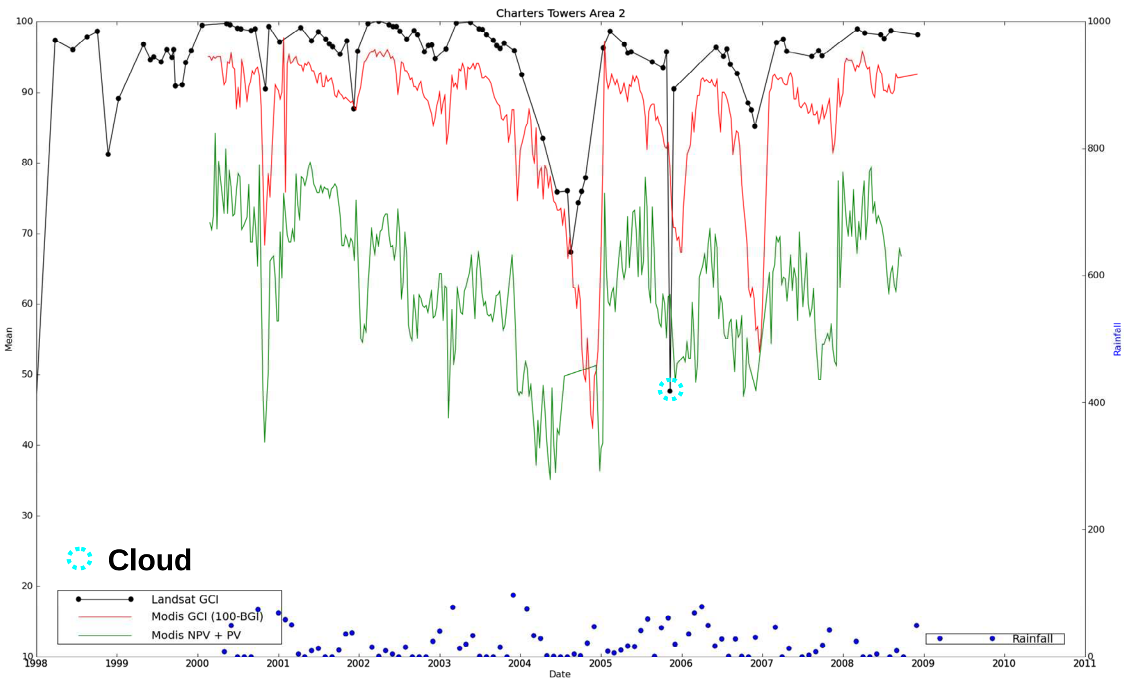

Figure 11 Ground cover data from Landsat GCI (Scarth et al., 2006), MODIS GCI (Milne et al., 2008) and MODIS NPV+PV (Guerschman et al., 2009) including rainfall data, for Region 2 Improved Pasture. Cloud affected images in the Landsat time series are indicated.

5.1.5. Region 3 Unimproved Pasture – patchy grass

Figure 12 shows the GCI exploration plot for the Region 3 Unimproved Pasture. This study site has a more patchy distribution of grass species than Regions 1 and 2. As with Regions 1 and 2, the three time-series products are showing relatively similar trends through time. There still remains a discrepancy between estimated absolute cover levels for the three products and there was one unexplained outlier in the MODIS fractional cover product.

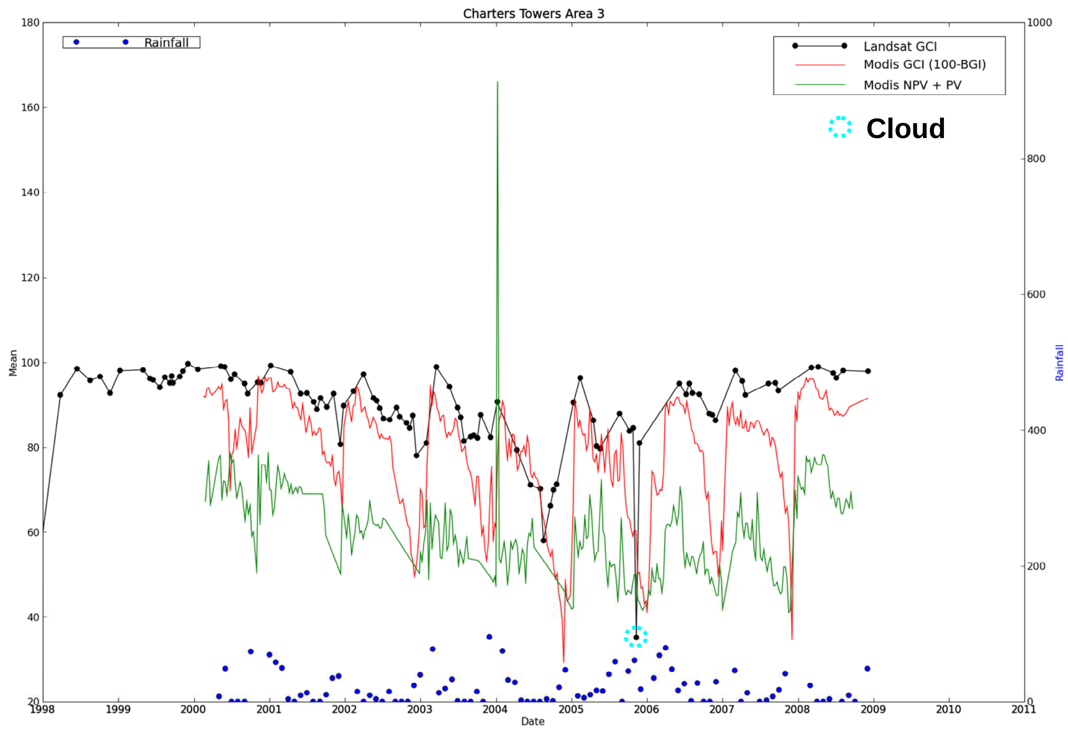

Figure 12 Ground cover data from Landsat GCI (Scarth et al, 2006), MODIS GCI (Milne et al, 2008) and MODIS NPV+PV (Guerschman et al , 2009) including rainfall, for Region 3 Unimproved Pasture. Cloud affected images in the Landsat time series are indicated.

5.2. Independent validation of the Landsat GCI

5.2.1. AussieGRASS

Figure 13 shows that the Landsat GCI and the AussieGRASS model estimated ground cover time series are similar in magnitude and highly correlated (R^2 = 0.98). The year 1991 was the largest outlier, possibly due to aerosol effects. The range of values observed reflects the influence of climate variability and grazing pressure at very large scales (Scarth et al., 2006).

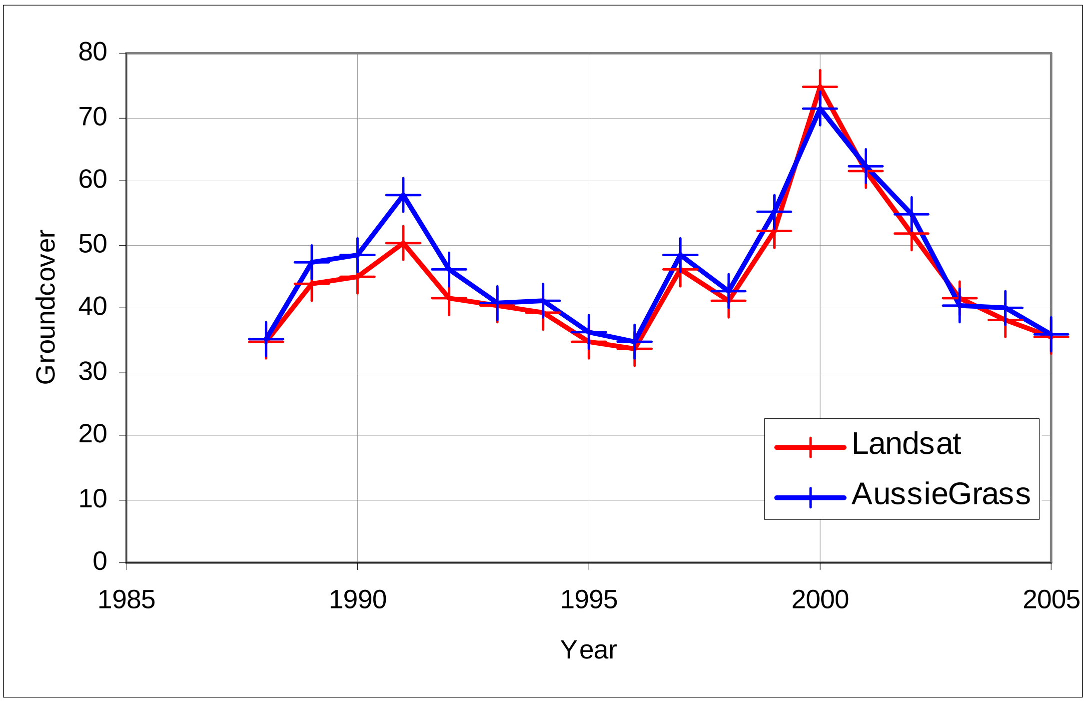

Figure 13 Temporal plots of Landsat derived and AussieGRASS modelled ground cover for all of Queensland (Scarth et al., 2006).

5.2.2. Grazing trial area in Keilambete

The average GCI in the cleared paddocks follows the same pattern as the field observed cover estimates, but has consistently higher estimates of ground cover with an average bias of +13% (Figure 14). The paddocks with trees display a higher bias with 21% in the GCI compared to the field observations.

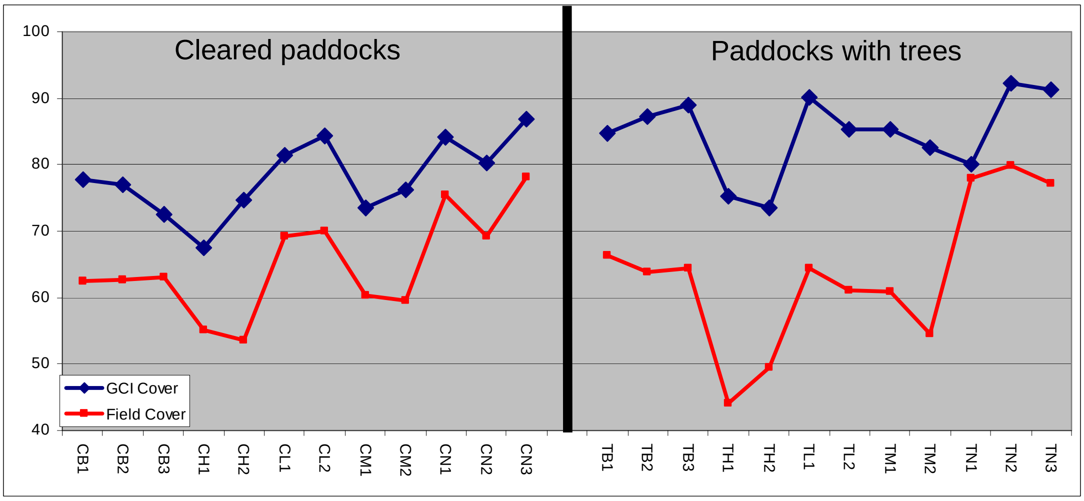

Figure 14 Independent GCI validation with mean GCI values over the grazing trial (1992-2001) (Silcock et al., 2005) in cleared paddocks (on average 13% higher) and paddocks with trees (on average 21% higher).

5.3. Sampling design and field data collection for calibration of ground cover estimated from satellite imagery

Figure 15 shows the fractional cover levels averaged for different sampling intervals measured on the first field trip. Assuming that a 5cm interval is the most accurate interval on which to measure ground cover fractions, it appears that the 55cm sampling interval with a diagonal transect represents the cover estimates with the minimum deviation for all three cover components. However, this interval length is impractical in the field. A 1m interval showed only a slightly higher error although the number of observations is low in the example.

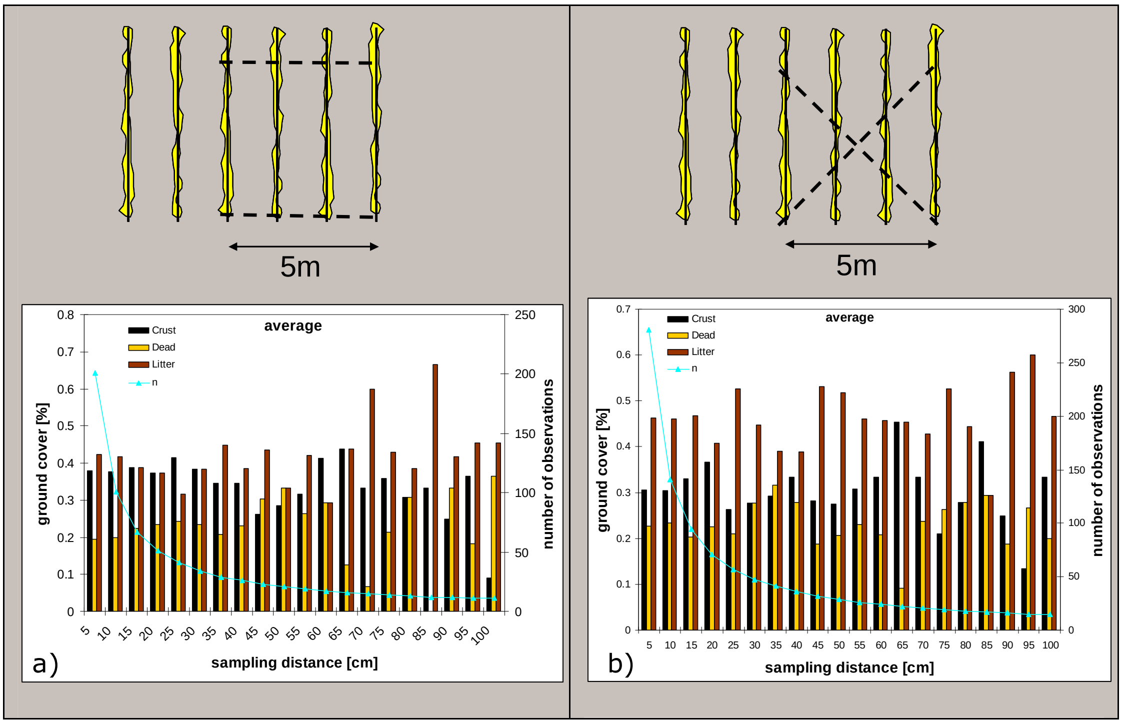

Figure 15 Fractional cover levels at different sampling intervals for transects that are a) orthogonal and b) diagonal to the rows

Table 1 shows summary statistics of the fractional ground cover measurements of the three different sampling designs trialled on the second field trip: the star transect of Figure 4 a), variable short transects of Figure 4 b), and the 45 degree across row sampling of Figure 4 c). The percentages of the measured fractional cover components are shown. A visual estimate of bare ground in the field by two independent operators was 60% and 55%. The measured bare ground quantities, sampled with the star transect and the 45 degree across row methods, were 62% and 58%, respectively. This coincides well with the independent visual estimates. The different short transects had a mean bare ground value of 41% and prove to be non-representative for the area, despite best efforts to select representative locations.

Table 1 Summary statistics of the different sampling designs as described in section 4.3. The sites with a transect length of 100m are highlighted.

Design	length	crust	disturbed	rock	green	dead	litter	cryptogam	bare [%] *
star	3x100m	0.57	0.05	0.00	0.37	0.00	0.00	0.00	0.62
cross	2x10m	0.68	0.02	0.00	0.30	0.00	0.01	0.00	0.70
10a	10m	0.22	0.02	0.00	0.75	0.00	0.00	0.00	0.24
10b	10m	0.29	0.00	0.00	0.67	0.01	0.02		0.29
10c	10m	0.38	0.02	0.00	0.59	0.00	0.00	0.00	0.40
45 degree	2x100m	0.52	0.06	0.00	0.42	0.00	0.01	0.00	0.58

*bare=crust+rock+disturbed

6. Discussion

6.1. The way forward - fractional cover estimates using Landsat

Fractional cover estimates of green and non-green vegetation will not only help to estimate the ground cover components, but they can also be used to infer different land management practices. Figure 16 shows an example of a preliminary data product being developed by the Queensland Remote Sensing Centre (QRSC) for fractional cover estimates of green and non-green components using Landsat imagery. The product has an overall Root Mean Square Error (RMSE) of 13%. The cover fractions were calculated for an example region near Charters Towers and the method is currently under review (Schmidt & Denham, 2009, in prep).

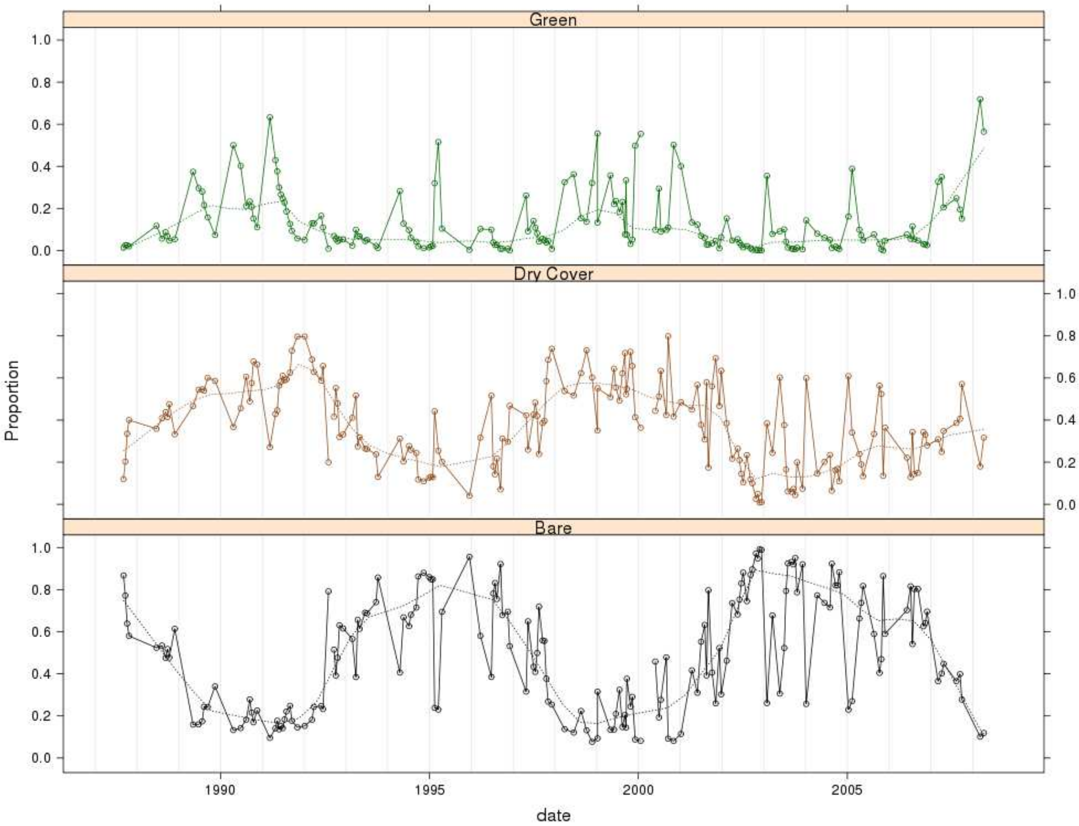

Figure 16 Fractional cover estimates where the cover fraction (1-bare) is spilt into green and dry cover for a Landsat time series near Charters Towers.

Figure 17 also shows an example of the Landsat-based fractional cover method of Schmidt & Denham (2009, in prep) for some agricultural areas near Goondiwindi. Validation based on data collected during three separate field campaigns showed high correlation (R^2 = 0.86) between the field data and the fractional cover product for the bare ground fraction. The GCI product for the same data resulted in significantly lower correlation coefficient (R^2 = 0.68). Validation of the PV and NPV fractions for the fractional cover method also resulted in high correlation (R^2 = 0.85 and R^2 = 0.89, respectively). These results are preliminary findings. Further analysis and validation is required in other locations and also during different growing seasons.

Another (second) method is also being researched and developed by the QRSC using spectral unmixing techniques. A further advantage of this approach is that the woody fractions can potentially be extracted for the product thus making it a truly integrated approach for mapping cover fractions. When these products become available, a comparison will be undertaken to determine which technique performs best across different environments.

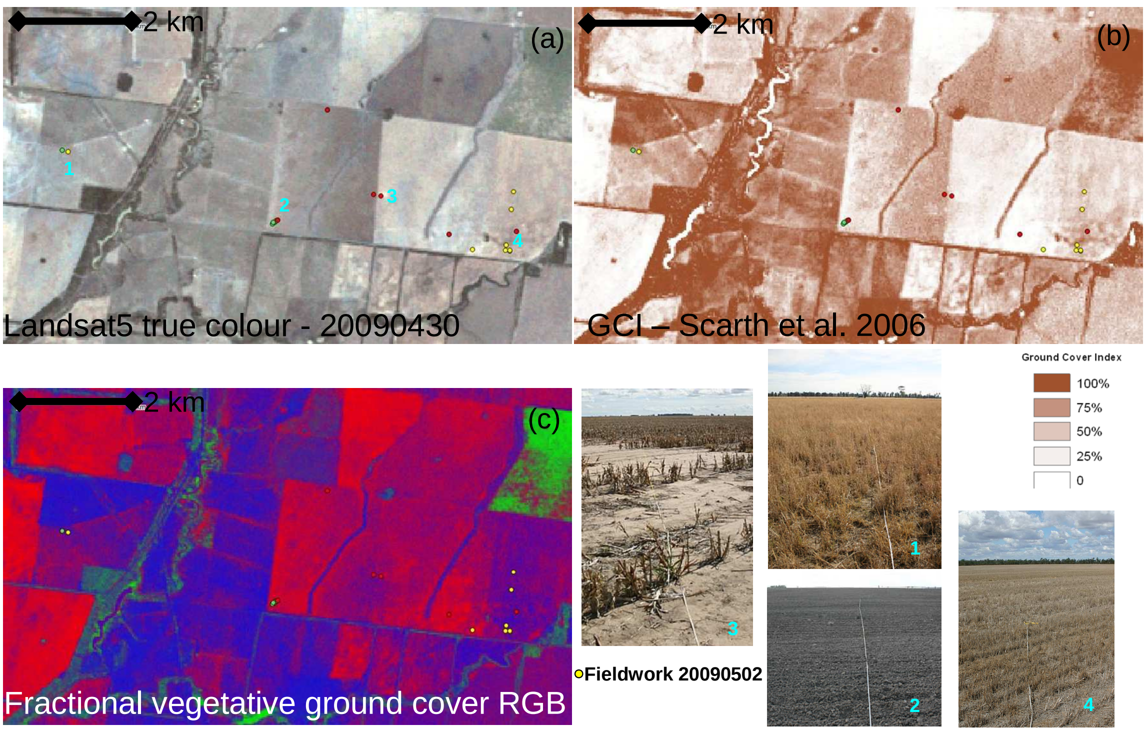

Figure 17 An example from near Goondiwindi, QLD, of a preliminary fractional cover mapping approach being developed by QRSC (Schmidt & Denham, 2009, in prep). (a) Landsat true colour composite (acquired 30/04/2009). Location of photos shown at bottom right are shown on this image. (b) The Landsat GCI product for the same image. (c) RGB colour space image of fractional ground cover product where: Red = bare ground; Green = photosynthetically active vegetation (PV); Blue = non-photosythetically active vegetation (NPV).

6.2. Field measurements and scale issues

The star transect approach has proven to be an effective sampling method of fractional ground cover in complex pastoral environments. Results here suggest that in less complex, intensive agricultural environments, the two 100m x 45 degree diagonal across row layout is an efficient and effective measurement technique in linearly sowed agricultural environments. The alignment with the sowing row ensures that the variation across rows is adequately sampled without bias to the alignment of the rows as could occur with the north-south orientated transect in the star transect design. It also represents an easily repeated and objective measurement for the 1ha scale required for calibration of Landsat imagery.

The method should be trialled further in other crop types and at different stages of the cropping cycle. Preliminary results suggest that the 100m cross-transect method works well in other crop types and crop planning geometries (e.g. sorghum) (Figure 18).

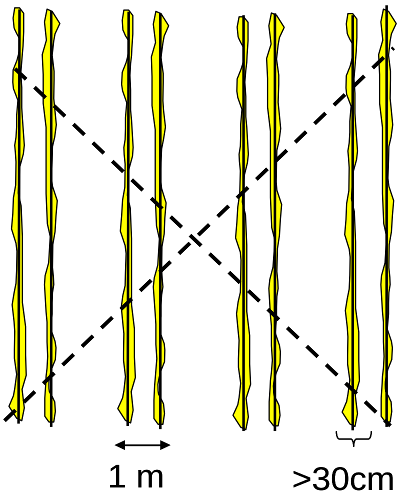

Figure 18: Sampling design suggestion for Sorghum with a double skip row.

6.3. Scale and temporal issues and sensor resolution

A sampling design for calibration of remotely sensed imagery is not only dependent on the regularity of the sowing pattern, but also on the scale of the sensor used. The methods trialled here are applicable for Landsat-scale ground cover calibration. These measurements are not directly transferable to MODIS for example, due to the resolution of the imagery. The field sampling methods required to sample a 3x3 pixel neighbourhood of 500m resolution imagery would be both impractical and unrealistic.

One transect at 1ha scale does not represent MODIS at 500m well, so it is recommended to use another, more representative sampling design or to use Landsat as an intermediate step to upscale to MODIS-type resolution.

One major disadvantage of using Landsat for seasonal (or better) monitoring of ground cover is the return interval of the satellite (16 days) and the temporal gaps in the time series due to clouds. MODIS has a daily return interval (composited over 8 or 16 days) which has the advantage of greater chance of cloud-free imagery and more regular sampling at key times during the cropping cycle when the quantities of cover are rapidly changing. The obvious advantage of using Landsat is the spatial and spectral resolution of the imagery. Many cropping areas incorporate small fields with a patchwork of crop types and management practices. The spatial resolution of Landsat compared with MODIS is far more suited to monitoring in these environments.

It is optimal that field sampling for calibration be coincident with the imagery to be classified. Rapid changes occur in cropping areas in response to growing seasons, climate and land management practices. Any field survey program designed to provide calibration data should therefore be undertaken ensuring to take into account the temporal aspects of the land management regimes, climate and growing phases, as well as the satellite imagery overpass dates.

6.4. Data management and availability of imagery

The Landsat archive and the MODIS archive constitute very large data sets in their own right. There are also a number of stages involved in processing the data to achieve ground cover products. This generates even larger data sets. The data must therefore be managed such that storage, naming conventions, processing capability and expertise are all developed and available before undertaking any national monitoring program. One data management model that will soon exist within Australia is the National Collaborative Research Infrastructure Strategy's (NCRIS) Terrestrial Ecosystem Research Network (TERN)/Auscover project (see: http://ncris.innovation.gov.au/Capabilities/Pages/TERN.aspx). This model will have data storage, processing and distribution nodes around the country and will draw upon the expertise and infrastructure that already exists in a number of groups for pre-processing, image correction and classification algorithms. Any implementation of a national ground cover monitoring program should be incorporated into this project's data management and distribution model.

The complete Landsat archive is still not freely available for Australia. MODIS is provided free of charge by the United States' (US) National Aeronautical and Space Agency (NASA). Recently the United States Geological Survey (USGS) and NASA have started to make available, free of charge, the Landsat archive that is held in the US. This currently extends back to around 2003 for Australia. Preliminary testing and analysis by the QRSC of Landsat imagery available through the USGS, has found that the radiometric and atmospheric corrections applied to the imagery are comparable to those used by the QRSC for the SLATS program. However, it appears that the geometric accuracy may be in error of around 17m, possibly due to the ground control used by the USGS for orthorectification.

The model the USGS have developed for providing access to the Landsat archive is a promising step towards having the full archive freely available. However, the USGS only hold around 40% of the global archive and it would be the responsibility of global partners to provide the archive data to the USGS so that it could become available through their distribution model. In Australia, this partner is the National Earth Observation Group (NEOG) (previously known as ACRES: http://www.ga.gov.au/remote-sensing/). An alternative would be to make the Australian archive available through TERN. Coordination and commitment at the national level is required to realise this and to ensure appropriate resources are made available to enable NEOG to open the archive such that it’s full potential can be utilised.

7. Conclusions

7.1. Comparison of ground cover products

- Any multi-temporal or hyper-temporal analysis of satellite imagery requires scientifically rigorous and consistent, automated geometric, radiometric and atmospheric corrections to be applied to all imagery.

- Landsat data have the appropriate spatial resolution for a ground cover mapping approach in agricultural areas, however, the temporal resolution of ‘one image per year’ which is currently available is very coarse and requires detailed land cover information for monitoring cropping sites. The hyper-temporal Landsat time-series of the Charters Towers area is well suited for model calibration and validation. These dense Landsat time-series are not currently available Australia-wide. The Landsat Global Archive Consolidation project may make this possible if NEOG are prepared to make the data they already hold in archive available to the United States Geological Survey (USGS) for processing and free release to the public.

- The Landsat and MODIS GCI time-series products follow a relatively similar pattern and trend.

- The MODIS GCI and fractional cover data have a greater dynamic range than the Landsat GCI data for the improved pastures due to a more frequent temporal coverage.

- The MODIS GCI data in the cropping areas have a lower dynamic range than the Landsat GCI. This is possibly the result of a bias from another land cover signal in the (composited) MODIS pixel due to the spatial resolution and potential intrinsic spatial error of the pixel location.

- Landsat GCI was developed and calibrated over field sites in the rangelands and improved pastures for erectophile grass types and will most likely produce unrealistic estimates for crops with a differing physiology. Further extensive field-based calibration sites are required for improved development of all image-based ground cover products.

- The MODIS fractional ground cover estimates based on Guerschman et al. (2009) are known to underestimate the cover conditions (especially NPV) in Queensland by as much as 39-54%.

- The MODIS fractional cover estimate time-series signal based on Guerschman et al. (2009) appear to be smoothed/delayed compared to the MODIS GCI time-series based on Milne et al. (2008) as they have used a different time-series compositing method with a sliding window.

- The two MODIS-based GCI products seem to describe a similar pattern of behaviour, although the MODIS fractional cover estimates based on Guerschman et al. (2009) have lower absolute cover values and also a lower dynamic range than the MODIS GCI values as reported by Milne et al. (2008).

- Outliers in the hyper-temporal Landsat time-series are due to a lack of cloud masking at the time of writing this report. The Queensland Department of Environment and Resource Management (DERM) has developed an automated cloud masking method for the multi-temporal Landsat archive and this will be improved on and applied in the near future.

- The dynamic range of the Landsat GCI data in the pasture areas is generally low. This may be due to the product having been calibrated with only one or two ‘end of dry season’ images and therefore is not fully representative of seasonal variations in pasture phenology and reflectance.

- The spatial resolution of 500m MODIS data was found to be too coarse for the applications tested in this report- only single pixels could reliably be identified in these areas. Further, the assumption that a MODIS pixel location is correct is not always true and thus presents problems for direct comparison with products with higher spatial resolution (e.g. Landsat GCI) averaged over the 500x500m area.

- 1km MODIS FPAR data are too coarse for any analysis as the individual pixels represent a mixture of land uses and reflectance signals, particularly in cropping areas.

7.2. Field sampling techniques

- Field sampling for calibration of remotely sensed imagery should occur as close as possible to the image acquisition date. The sampling should take into account the spectral, spatial and temporal aspects of the sensor to be used.

- The field sampling should be stratified and designed to account for the variability in climate gradients, soil types and regional environmental parameters that influence cropping and improved pasture practices.

- The methods should be designed so that they can be applied consistently. The sample design needs to measure cover fractions along transects of appropriate length and orientation. Adequate replication of transect measurements needs to occur to sample the variability in ground cover fractions within and between crops or improved pastures through time.

- Based on the results of this study, the most appropriate sampling design for pasture and improved pasture areas is the star-transect design described by Scarth et al (2006). In less complex, intensive agricultural cropping environments, two 100m transects in a 45 degree diagonal across-row configuration is an efficient and effective measurement technique in linearly-sowed agricultural environments.

This finding is based on limited samples, spatially and temporally, and in terms of representativeness of different cropping systems and crop cycles. Further studies should be undertaken to assess the applicability of these designs in other agricultural regions around Australia.

8. Recommendations

i. The Commonwealth and States should fund a scoping study to identify user needs. The report by Leys et al. (2009) identified ground cover as a major issue for a number of regional groups around the country and a number of expert workshops have been held to discuss ground cover and land cover mapping and monitoring methods. However, to date, there has been no national survey to understand the needs of all end-users.

ii. A comprehensive literature review should be undertaken to understand national and international approaches to remote sensing of ground cover and field sampling design, particularly for cropping areas.

iii. Further research should be resourced to investigate the influence of climate and land management practices on fractional cover dynamics. De-coupling these effects will help to understand natural and human-induced variability in ground cover levels and provide for better informed policy and natural resource management.

iv. The Landsat-based GCI provides the spatial resolution required for monitoring ground cover in cropping areas. The report by Leys et al. (2009) identified fractional cover estimates as being priority data for erosion monitoring and modelling. New fractional ground cover products using Landsat or sensors at a similar spatial resolution should be developed and implemented across Australia. These products could be augmented by MODIS-based products to provide the temporal resolution sometimes required to adequately monitor intensive agricultural systems. It is much easier to scale up from Landsat to MODIS than the reverse.

v. A national program for field sampling of fractional ground cover should be costed and implemented. This program should incorporate the requirements for calibration sites for the remote sensing programs identified in this and other studies. The resourcing of this program should be adequate to encourage ongoing collaborative participation by all states and territories. The program should be developed with a vision for long-term monitoring to understand complex natural and modified environments, not short-term fiscal or political agendas.

vi. A set of standard, national protocols should be developed for field sampling of fractional cover that includes quantitative sampling of fractional cover based on techniques that can be trained and applied easily and consistently across the nation.

vii. The field sampling program should also consider the requirements of other state and national initiatives for environmental sampling and monitoring.

viii. A spectral library should be developed for land cover types in Australia that captures the spectral characteristics of each land cover type at various stages of dynamic phenological cycles.

ix. Any remote sensing monitoring that is designed to understand systems that incorporate land management practices should be informed by those land management practices and their variability and implementation. A comprehensive, spatially explicit, national database of land management practices is required to complement and inform the remote sensing products. The Land Use and Management Information System (LUMIS) Business Case should form the basis for this.

x. The ground cover products should be used in conjunction with other remote sensing products used to monitor cropping practices.

xi. The resources required to make the Australian Landsat archive freely available should be scoped and sourced. This is currently a major impediment to a number of long-term monitoring programs in Australia.

xii. A national Landsat-based ground cover monitoring program and accompanying calibration field program should be developed in collaboration with all states and territories. The NCRIS TERN/Auscover project has the potential to facilitate and provide the infrastructure and expertise for this collaboration.

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