Ground cover assessment 2012

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Final Report - Ground Cover Assessment 2012

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Executive Summary

This project aimed to provide information based on remote sensing products for ground cover monitoring at catchment, sub-catchment (landsystems, Socio- Economic System (SES)) and project scales. It was based on Landsat 5 & 7 satellite imagery which is available at no cost. The Western Catchment Management Authority (WCMA) was interested in monitoring ground cover against catchment targets and reviewing the impact of its investments on the amount of ground cover present.

The project has demonstrated the ability to monitor ground cover using a range of Landsat based products. It builds on an existing investment in research over 10 years by New South Wales and Queensland governments, the Lower Murray Darling and Namoi CMAs, Queensland regional groups and the Commonwealth Department of Agriculture Forestry and Fisheries.

The existing fractional cover model provided by the Joint Remote Sensing Research Program (JRSRP) was revised in December 2012 to incorporate many more calibration sites acquired during the Ground Cover Monitoring for Australia project run by Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) and additional sites from the Namoi CMA project. The addition of these sites allowed a considerable refinement of the model and improved the accuracy and reliability of the model.

Additional field sites within the WCMA were also collected as part of this project. These site measurements have been used to validate the existing fractional ground cover model. An additional nineteen field sites were measured as part of this project. Site measurements were taken in accordance with the established and well documented method (Schmidt *et al.,* 2011) that has been developed and improved over 10 years. This field method is also being used as the national standard in the Ground Cover Monitoring for Australia project (Muir *et al*, 2011). The field sites were co-located on existing WCMA MER project monitoring sites with an established land holder relationship. WCMA had existing treatment and control paired sites for areas receiving incentive funding so it was possible to use these locations for site measurements.

Landsat 5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper (ETM+) data were acquired from the United States Geological Survey (USGS) and used to create the ground cover products in this project. Catchment wide, annual, summer ground cover mosaics were generated for the 2006–2013 period. In addition to this for three nominated standard Landsat scenes, seasonal (4 per year) median groundcover layers were generated for the period 2006–2013. This is a new product, not used in previous ground cover reports.

Property reports were produced for areas of CMA investment. These reports demonstrate how the treatment and control sites on each individual property compare through time for each fraction of cover.

The potential to use the recently launched Landsat 8 to continue monitoring ground cover in this manner is a significant benefit.

1 Introduction

The aim of the project was to provide information based on remote sensing products for ground cover monitoring at catchment, sub-catchment and project scales. The Western Catchment Management Authority (Western CMA) covers a large geographic area and has a wide variety of land use and land covers. Due to its size and complexity monitoring and reporting on a variety of biophysical parameters is an important component of the Western CMA operations. The ability to report on the entire catchment on a regular interval provides valuable information to the Western CMA.

The products presented in this report are based on Landsat 5 & 7 satellite imagery which is currently available at no cost. The Western CMA is interested in monitoring ground cover against catchment targets and reviewing the impact of its investments on the amount of ground cover present. This information and products provided with this report, provides information on changes in ground cover through time in a user friendly manner for the Western Catchment.

The project has demonstrated the ability to monitor ground cover using a range of Landsat based products. It builds on an existing investment in research over 10 years by New South Wales and Queensland Governments, the Lower Murray Darling and Namoi CMAs, Queensland regional groups and the Commonwealth Department of Agriculture Forestry and Fisheries. The potential to continue monitoring of ground cover in this manner, potentially with more specialised products into the future is significant.

2 Method

The method is based on that described by Scarth *et al*. (2010). It uses radiometrically corrected Landsat TM and ETM+ imagery together with site measurements to map ground cover fractions (green, dead and bare). This method has been developed over 10 years. Initially it was developed in Queensland, and in recent years has been extended to NSW through collaborative projects with the Lower Murray Darling and Namoi CMAs. The ongoing model development is now undertaken by the Joint Remote Sensing Research Program[1] (JRSRP) based at the University of Queensland in association with OEH and equivalent departments from Queensland and Victoria. There is also a commitment by the JRSRP to implement this method so that annual ground cover products are made available through the Terrestrial Ecosystem Research Network (TERN) Auscover portal[2], ensuring access to updated ground cover products in future.

An important part of the method is the pre-processing methods that have been developed for image calibration and radiometric correction (Danaher, 2002). The corrections enable the analysis of imagery from different locations and time periods.

The ground cover model approach uses an un-mixing approach based on site measurements to predict green, dead and bare cover fractions for every pixel in a Landsat image. Based on existing analysis, the standard error of prediction is less than 10% for each or the green, dead and bare fractions. An example of these products from western NSW is shown in Figures 1 and 2.

[1] http://www.gpem.uq.edu.au/jrsrp
[2] http://www.auscover.org.au/

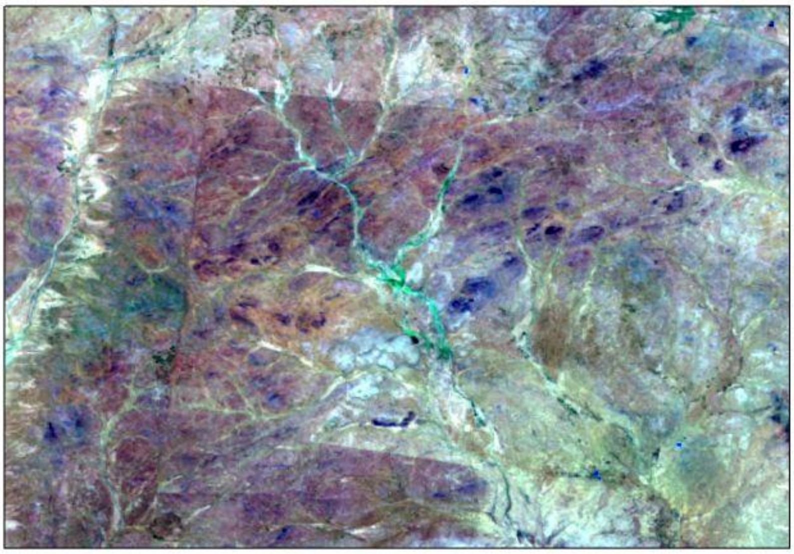


Figure 1: Landsat 5 TM image showing bands 5 (Red), 4 (Green), 2 (Blue)

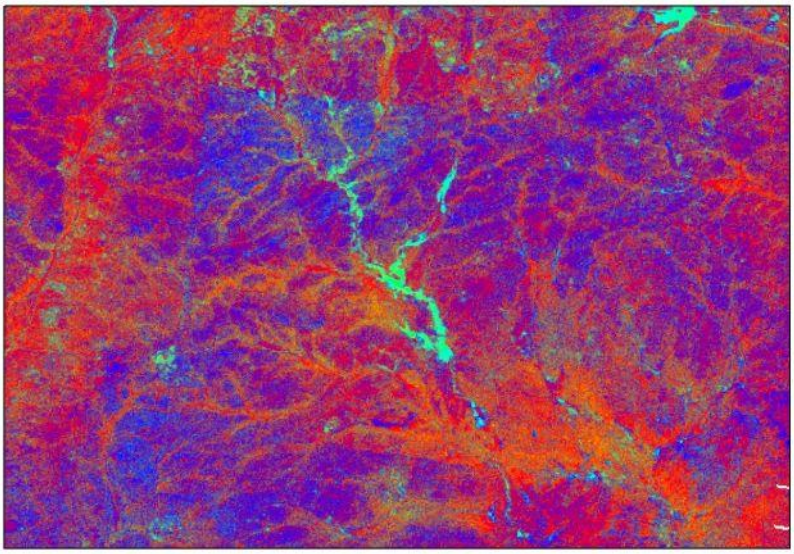


Figure 2: Cover components image showing bare (Red), green (Green) and dead (Blue)

3 Data acquisition and pre-processing

3.1 Satellite imagery acquisition

The Landsat satellite images used in this project were acquired at no cost from the United States Geological Survey (USGS). Both Landsat 5 and Landsat 7 images were used, however, Landsat 7 ETM+ sensor has been operating without Scan Line Compensation (SLC off) since 2003 so there are gaps in the Landsat 7 images as indicated in Figure 3. Landsat 7 ETM+ data is being used because Landsat 5 ceased operation on the 18^{th} November 2011. This meant that in order to acquire images after that date, Landsat 7 ETM+ was the only option.

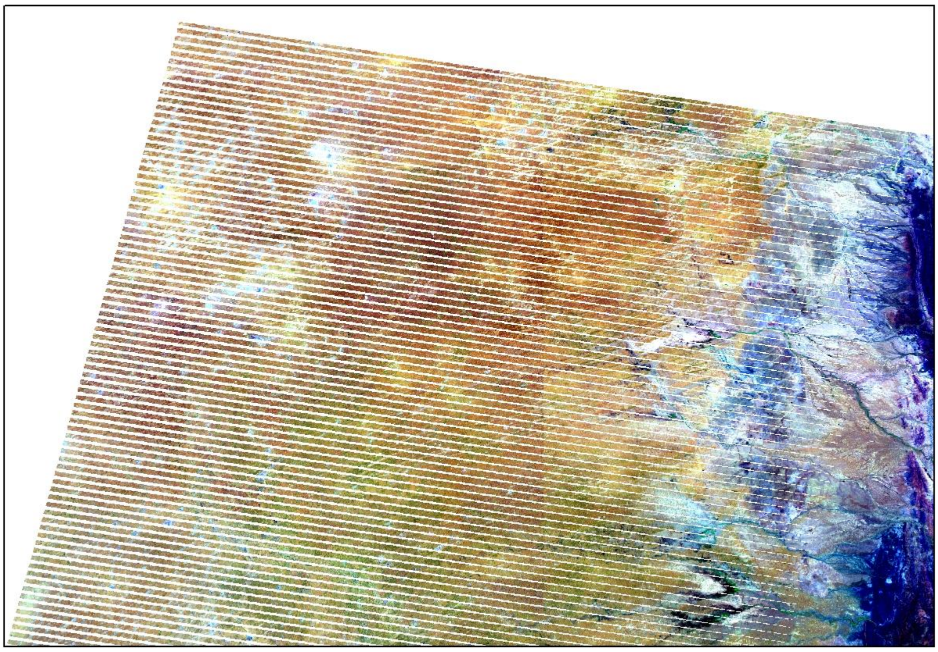


Figure 3: Appearance of SLC off Landsat 7 ETM+ image showing missing data

Satellite images were selected to enable the development of time series of seasonal ground cover products for the eighteen Landsat scenes that cover the Western CMA area of operations. Figure 4 shows the path/row extents for the Landsat scenes selected. The images were selected to minimise the cloud cover present and maximise the time period between the date of rainfall events and image capture. In some cases, where there was missing data due to cloud cover or the use of Landsat 7 SLC-off images which have gaps so more than one image over the same area was acquired to fill the gaps. These images were processed to generate fractional cover and merged to create the summer seasonal image.

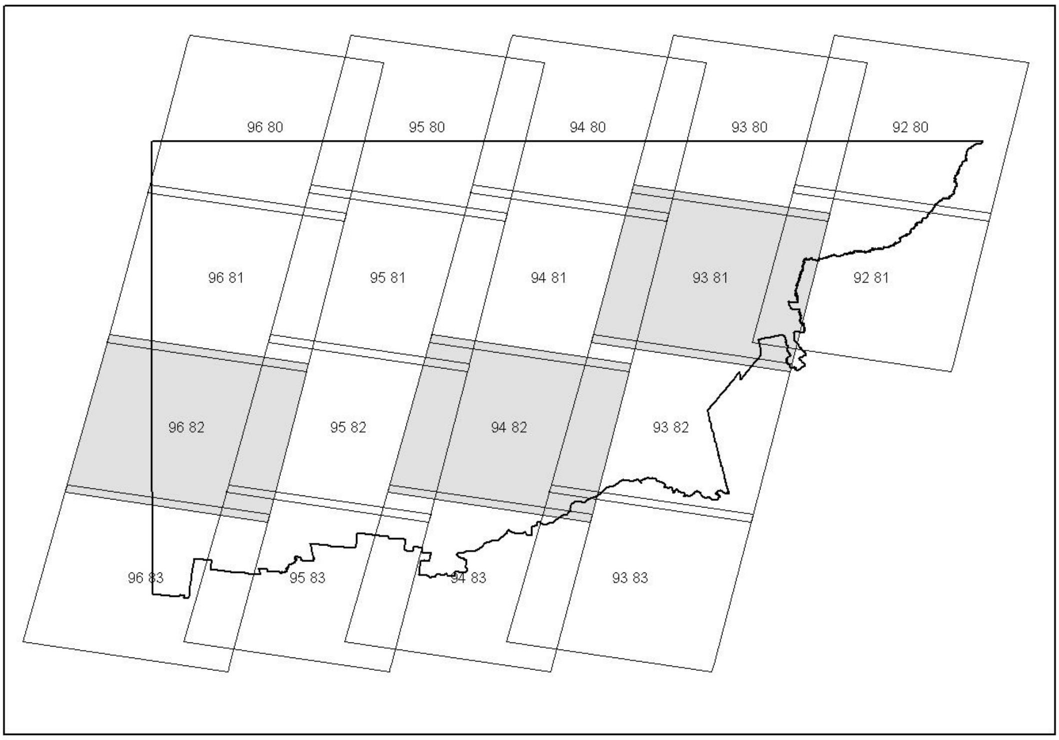


Figure 4: Landsat Path Rows selected for analysis for WCMA.

Additional scenes were acquired for three scene footprints (depicted in light grey in Figure 4) to create a more dense time series. For the three scene footprints selected at least four scenes for each season were gathered to allow calculation of a median value for each pixel. These additional scenes covered the date range of summer 2006 to summer 2013.

Images were also required for the validation of the satellite products. These site measurements were taken as close as possible to satellite overpass dates. The maximum difference between taking ground measurements and satellite image overpass was three days with the average time difference being one day. For some sites the field sites were in areas of the image that were cloudy or affected by the SLC-off problem. In these cases an alternative image date was used. These alternative images were up to 22 days different to the field measurement date with an average of 16 days.

The imagery was downloaded from the USGS using the Global Visualisation Viewer (Figure 3) to the OEH remote sensing computing cluster at AC3 in Redfern, Sydney. The full list of images used is contained in the Appendix 2.

Figure 3: USGS Glovis tool showing the location of Landsat scenes covering Western CMA region with catchment boundaries shown in red

3.2 Satellite imagery pre-processing

The Landsat images acquired from the USGS are provided as ortho-rectified images so no further geometric correction is required. All other pre-processing of these images was done at the OEH remote sensing computing cluster at AC3. Images were converted to top-of-atmosphere (TOA) reflectance and a three-parameter empirical model applied to further reduce variation in scene-to-scene illumination geometry and bi-directional reflectance distribution function (BRDF) (Danaher, 2002). This step enables the comparison of image values from images acquired at different times and in different locations.

Masks were created to remove areas affected by cloud, cloud shadow, smoke, water or topographic shadow. All masks except for cloud and cloud shadow are implemented as automated methods. The cloud and cloud shadow masks produced by automated methods require further visual editing which can be a very time consuming where there is considerable cloud in an image.

All imagery is named according to the SLATS file naming convention (OEH, 2012) to enable automated processing of the imagery. The filenames are of the general form *what_were_when_processing stage*. Later in this report, products are referred to by the processing stage e.g. "di7" which forms the *processing stage* part of the filename.

4 Field site selection and measurement

Site data were required to enable the validation of Landsat-based ground cover models. The primary aim was to select site locations covering a range of soil and vegetation type in the Western CMA area of operations and also covering a range of ground cover and greenness. One major constraint on site location was the lack of complete image coverage, which is an issue when using Landsat 7 images. The centre 30 km strip has complete image coverage within a single image but there are gaps in the data which increase in size towards the edge of the image. As a result, the sites were clustered in the centre strip of the image.

The sampling strategy was done by visual interpretation using the expert opinion of OEH remote sensing staff. Sites were located on top of existing CMA MER sites. Property owner contact details were provided by the CMA so owners could be contacted in advance of fieldwork. Often it was possible to measure multiple sites on a single property in treatment and control pairs.

The method used to collect the site data is based on the SLATS approach (Danaher *et al.*, 2011) developed in Queensland. Sites are set up as star transects, each 100 m long, and set out at 60° intervals (Figure 4). The centre of the star is located using a averaging GPS. This is a useful configuration, as it is efficient in practice and the area it samples can be readily linked to high and moderate spatial resolution imagery, such as Landsat TM. Ground cover, foliage projective cover (FPC) at mid and upper-storey, and crown cover (CC) are sampled every 1 m along each transect. A vertical sighting tube was used to sample the overstorey and mid-storey FPC and CC. A laser pointer was used to sample the ground cover. Ground intercepts were classified by the observer as bare soil, rock, cryptogram or live or dead ground cover. Canopy intercepts were classified as tree and/or shrub green leaf, dead leaf, branch, or sky.

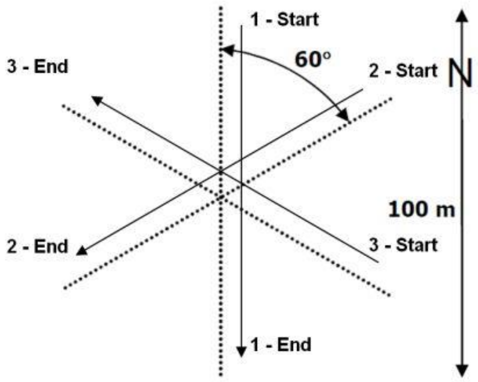


Figure 4: Field site transect layout

This field site measurement method has become a standard for remote sensing based ground cover measurement in Australia and is being used by state and commonwealth organisations. A handbook (Schmidt *et al.*, 2011) describing the method was written for the Ground Cover Monitoring for Australia project being coordinated by ABARE-BRS.

The measurement of the vegetation sites were made by OEH remote sensing staff from Dubbo. All the staff involved in the field work were familiar with the ground cover field measurement techniques and had previously been trained and were provided a copy of the field measurement handbook (Schmidt *et al.*, 2011) to review before commencing fieldwork. The field campaign took place in two halves with an eastern and a western campaign. The field campaign was undertaken in at the same time as the MER sites were being revisited in association with the OEH staff contracted to perform the MER fieldwork.

The field sites were measured from early 18th to the 21st February and the 4th to the 7th March 2013. The location of the sites measured sites is shown in Figure 5. A total of 19 sites were measured.

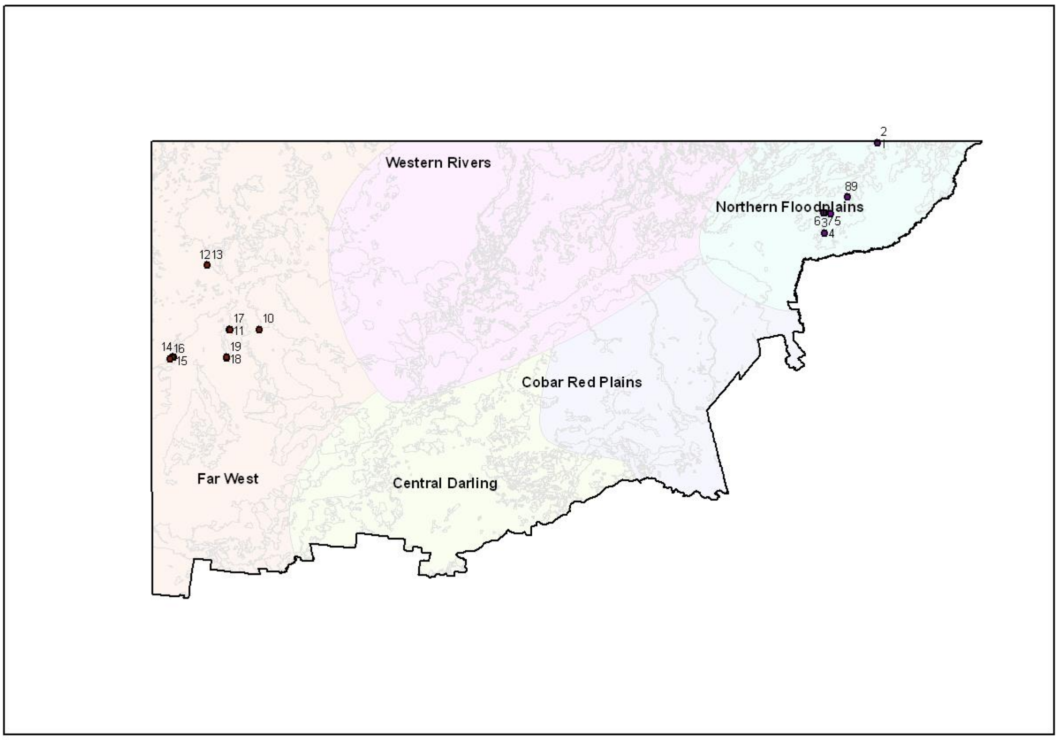


Figure 5: Location of field calibration/validation sites

The photos in Figure 6, below, shows a range of cover types where sites were measured as part of the project.

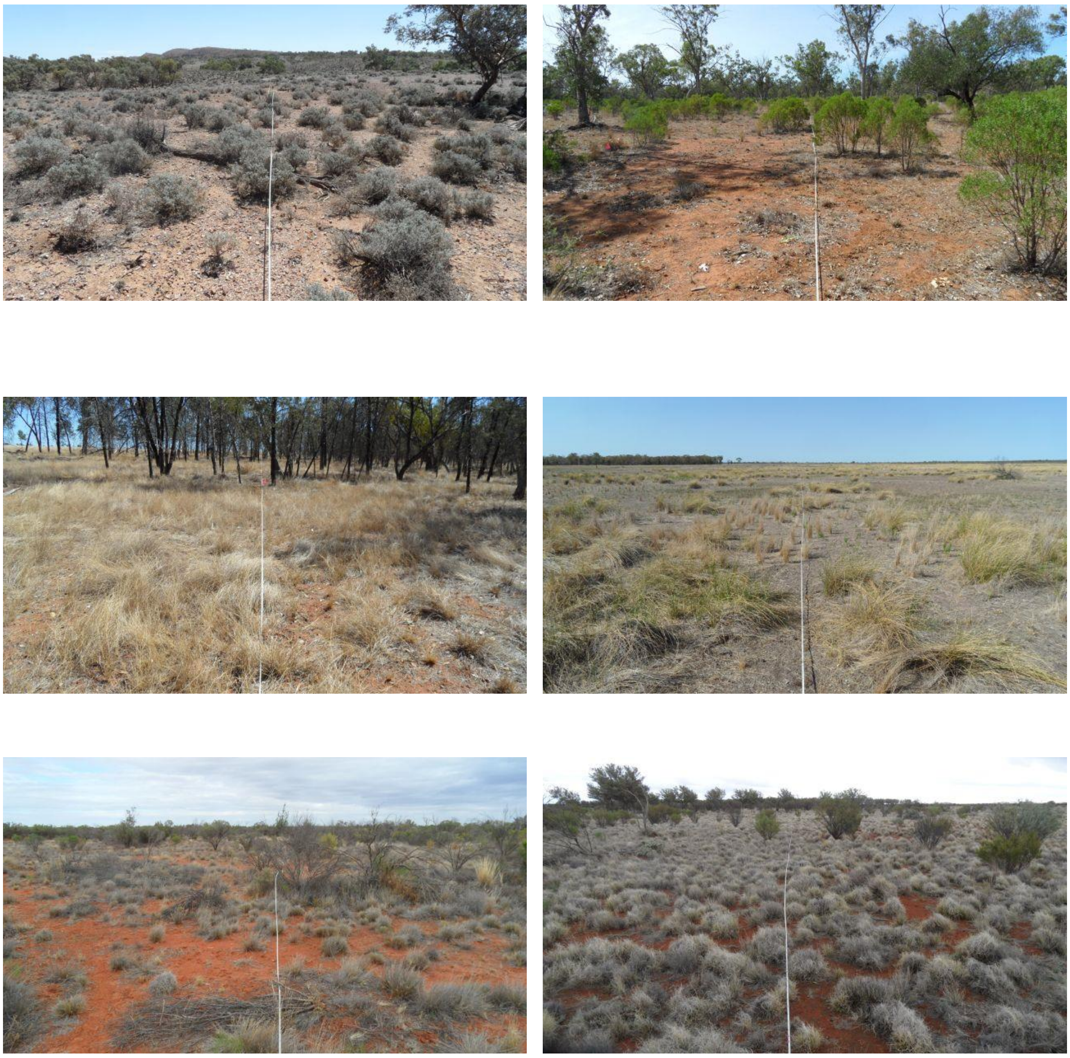


Figure 6: Examples of field sites measured

5 Data analysis and validation

5.1 Fractional cover products

This section of the research was done by the JRSRP at the University of QLD. OEH is a partner in that program. The method was initially reported by Scarth *et al.* (2011).

The methods used to predict fractional cover from remotely-sensed images generally rely on having a good library of spectral signatures, which shows the light signature for each land-cover component of interest. The spectra is usually collected in the field using a spectrometer or from the image itself. The term "endmember" assumes that it is a pure component, so in the case of ground cover a pure bare component has to be pure bare soil, a pure green component contains entirely green plant material and a pure dead component is composed of dead leaves, senescent vegetation and/or litter only, with no soil background visible. It is rare to find a pure 30 m x 30 m Landsat pixel in a heterogeneous rangeland environment. Therefore, to characterise the inherent variability in rangeland environments it is necessary to develop methods to derive synthetic endmembers from field data representing impure pixels.

To determine the spectral signatures of the three endmembers, the known reflectance in a pixel is modelled as a weighted sum of the unknown spectral signatures of the bare, green and dead components, where the field-measured fractions are the weights. Given there are many more sites than there are endmembers the model can be solved (inverted) and in doing so provide the synthesised spectral signatures of the endmembers.

Once the spectral signatures of each endmember are determined a linear spectral unmixing method can be used to predict the fraction of each endmember within each pixel of an image. The same weighted model is used as before, except that it is solved for the unknown fraction within each pixel. The model, however, is constrained so that the sum of the fractions is one. This constraint is necessary as the synthesised signatures are only optimal at the training sites.

The training data used for this model includes sites measured between 2000 and 2013 over areas in Queensland and NSW. All sites were measured using the same SLATS field methodology used in this project. The result of the model is shown in Figure 7. This final model has a root mean squared error of 11.8% and a squared Pearson product moment correlation coefficient of 0.82. This result indicates that the model fits very well and the overall root mean square error, particularly in the mid-cover region, is an improvement on the ground cover model used in the 2009 LMD study (Scarth *et al.*, 2006).

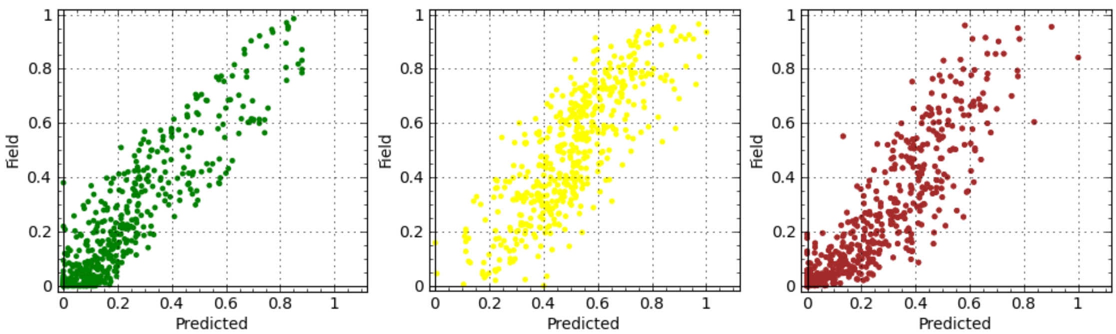
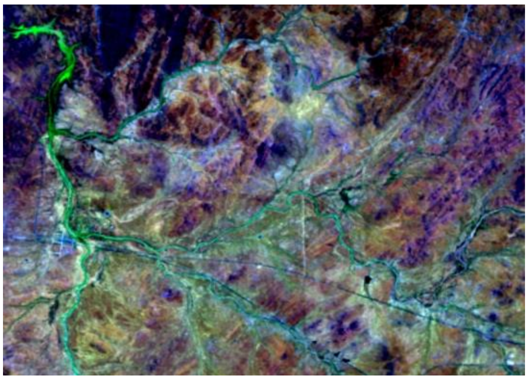


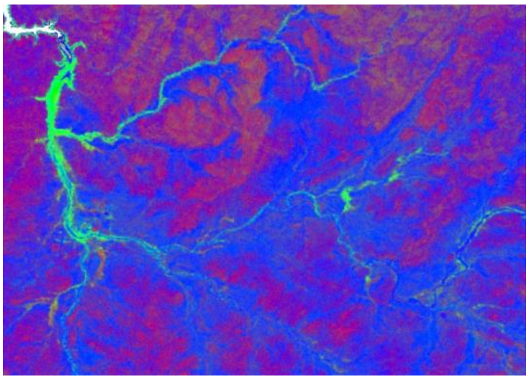
Figure 7: Observed vs. predicted graphs showing model fit for green, dead and bare ground cover components. This model has a RMSE of 11.8% and an R^2 of 0.82

5.2 Single date fractional cover products

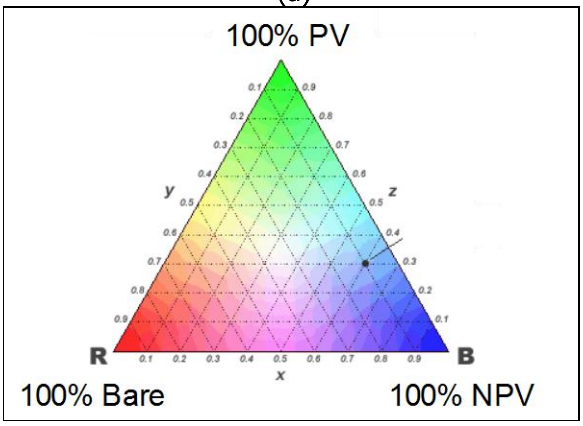
The fractional ground cover model described above was applied to every Landsat image acquired over the Western CMA area of operations. The fractional cover or "di7" stage image includes four bands: predictions of bare cover; green cover; dead cover; and a residual component that the unmixing method couldn't allocate to one of those components. Figures 8 shows an example of a fractional cover image displayed with the cover components bare, green and dead as red, green and blue. The image colours represent a mix of these fractions as shown in Figure 8(c). For this project, subsequent processing was based on the "die" stage images that are the bare fraction from the "di7" images with cloud, cloud shadow and water masks applied.

Where more than one image was required to represent seasonal ground cover for a scene due to cloud or Landsat 7 SLC off gaps, multiple "die" stage images were merged to create a single seasonal image. This was done by first including the pixels from the best image then adding pixels from other images in order of preference. These images were given a nominal date, which was the date of the image which provided most of the data. In addition to the merged image a pointer image ("diz" stage) containing the date of every pixel in the merged image was also created.





(a) (b)



(c)

Figure 8: (a) Landsat TM image with bands 5,4,2 shown as RGB (b) ground cover components image for 8th April 2011 with dead, green, bare bands shown as RGB (c) legend for cover components image, PV = photosynthetic vegetation (or green) NPV = non-photosynthetic vegetation (or dead)

The summer seasonal scene images for each of the 18 Landsat scenes covering the Western CMA area of operations were then mosaiced to form catchment wide masked fractional cover images ("die" stage) These mosaics were produced with images added North-South and East-West with last overlay taking precedence (placed on top in the final mosaic) using the gdalmerge[3] utility. The map projection used for these mosaics was NSW lamberts. Mosaics of the "diz" pointer images were also created. A list of all images used for these products is included in Appendix 1.

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[3] http://www.gdal.org/

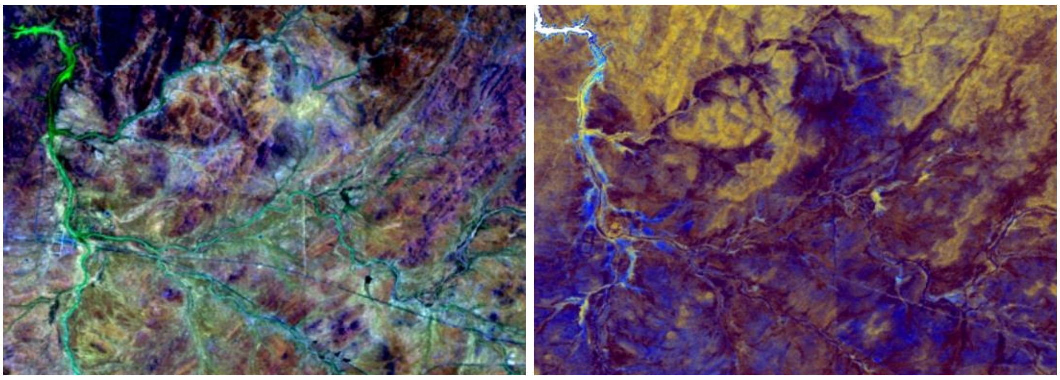
[3] http://www.spatialreference.org/ref/epsg/3308/

5.3 Catchment wide fractional cover mosaic products

Where a time series of fractional cover images exist it is possible to generate products that represent the time series as statistical images. This approach is usually applied to a time series of images spanning many years to identify areas with higher or lower than average cover. For this project there were eight summer images for the period 2008–13 available. A multi-date fractional cover product was created.

The single date or merged "die" images were combined to generate an image product based on the time series statistics. Only the ground cover (1-bare fraction) was used in this analysis. The "dip" stage is a five layer (byte) image with the 5, 50 and 95 ground cover percentiles of the beta distribution calculated using the statistics from the mean and standard deviation from the time series "die" image stack. The bands are: 5th percentile, or 'minimum' (band 1), 50th percentile, or 'mean' (band 2), 95th percentile, or 'maximum' (band 3), standard deviation (band 4), number of observations (band 5). These were then mosaiced to form a catchment wide ground cover percentile images.

An example of time series percentile product is shown in Figure 9(b). The image is a composite or the minimum ground cover (5th percentile), mean and standard deviation of the ground cover based on all summer images. The image clearly discriminates the areas that were cropped during the 12 month period based on the standard deviation of ground cover. The yellow areas are those with less variable ground cover such as pasture and woody areas. Within these areas the darker tones represents lower ground cover.



(a) (b)

Figure 9: (a) Landsat TM image with bands 5, 4, 2 shown as RGB (b) Time series ground cover composite image with minimum cover (5% percentile), median ground cover and standard deviation of ground cover (over the eight summer season images) shown as RGB

5.4 Seasonal scene based fractional cover products

Three scenes were selected in consultation with WCMA staff for detailed seasonal analysis. The location of the three scenes are presented in Figure 10

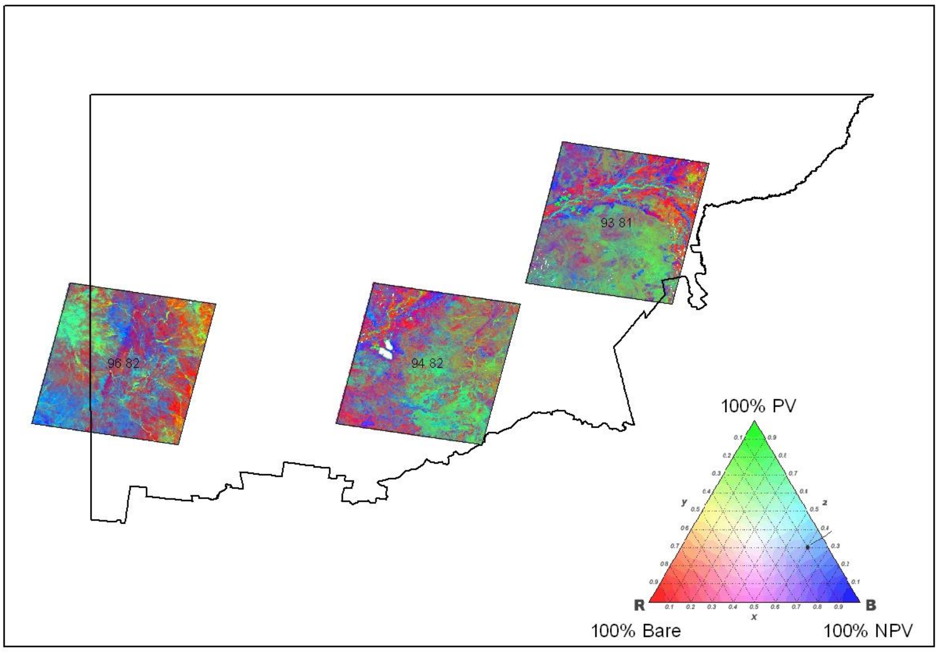


Figure 10: Location of the three selected scenes for seasonal analysis

For each of the selected three scenes at least three images per season were acquired and processed. These images were then stacked and a median value determined for each pixel in each season over the period 2006–13. The median value has previously been determined to be a good measure of seasonal variability. The seasonal fractional cover image is a composite of individual-date fractional cover images within a calendar season. We choose four calendar seasons: Summer – December to February; Autumn – March to May, Winter – June to August, Spring – September to November. The date format in the imagery identifies these seasons. The date format is mYYYYMMYYYYMM. For example:

Summer 2008 - m200712200802,	Autumn 2008 - m200803200805
Winter 2008 - m200806200809 ,	Spring 2008 - m200809200811

For each grid point within the scene, the processing selects the medoid pixel from all available pixels within the season after masking (cloud, shadow, and water). The medoid pixel is determined in two steps. Firstly, the multi-dimensional median is calculated; this is simply the median of each of the bare, green, and dead fractions. Secondly the distance of all pixels to the median is computed. The medoid pixel is the one with the shortest distance to the median. A publication on this method, showing that the medoid provides a good estimate of the seasonal conditions, is forthcoming.

The seasonal fractional cover components allow a much more detailed analysis of the variability of the ground cover fractions through time and allow comparisons between seasons other than the Summer catchment wide fractional cover data. The process is more computationally intensive, however automated procedures are being developed and the production of seasonal cover products will become routine.

6 Validation of fractional cover model in Western CMA

Analysis of the measured field sites and the fractional cover values was undertaken.
The measured values for each fraction were plotted against the relevant fraction predicted from Landsat 7 images, producing Figure 11 below. The 19 sites each had measurable, green, dead and bare values, yielding 57 points for comparison. Table 1 indicates various attributes for each site measured including the date difference between ground measurement and the image from which the fractional cover values have been extracted.

There is a range of date differences due to imperfect image acquisition situations such as clouds and SLC off imaging mode. This means that although the fieldwork was planned co-incident with satellite overpass, images from the pass before or after were used when data was not captured at the optimum overpass date to the aforementioned cloud and SLC off problems.

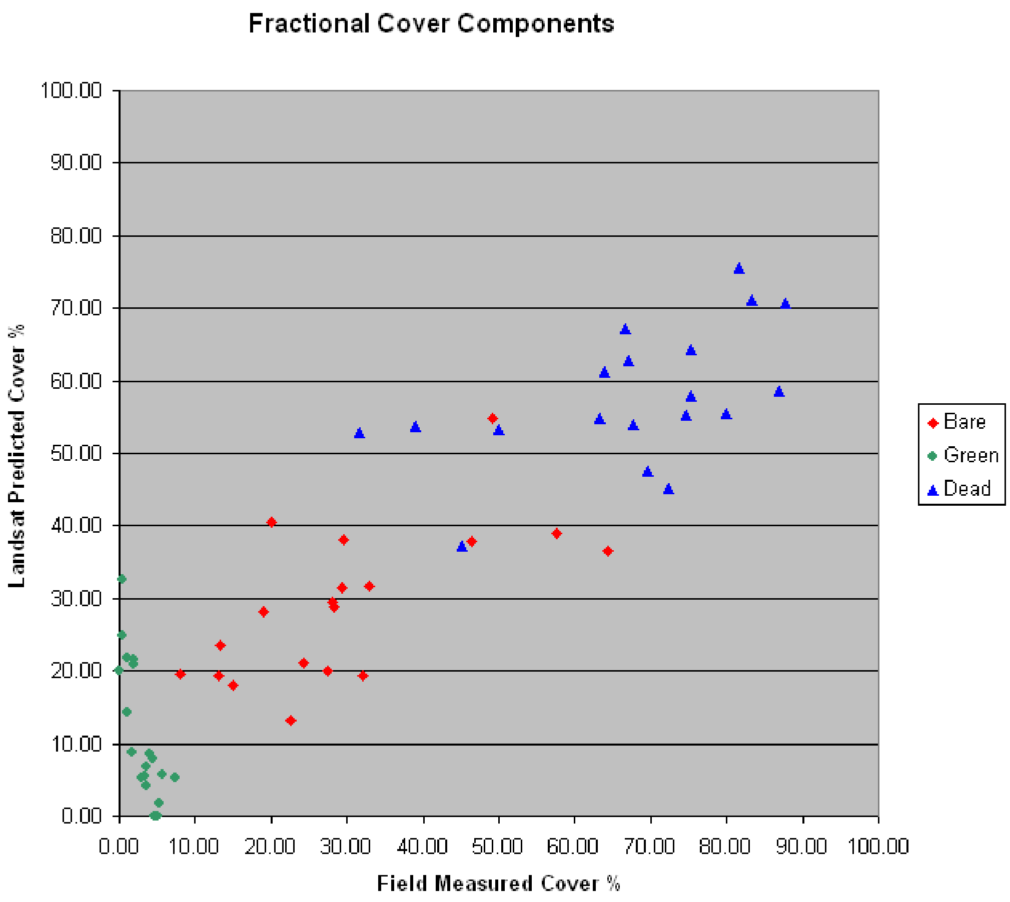


Figure 11: Validation of fractional cover products using Western CMA site data

In general the comparison appears a reasonable fit, with the exception of a cluster of high green image fraction values on the Y axis around the 20 to 35 percent value. These measured sites correspond to sites with a high tree or mid storey cover. The high green value in the image relates to the high tree cover obscuring the low measured green values of the ground cover layer, and contributing a high green return.

Site	Date	Longitude	Latitude	Image used for value extraction	Image Bare	Image Green	Image Dead	Ground Bare	Ground Green	Ground Dry	Mid Storey Cover	Over Storey Cover
WST001	20130218	147.9574	-29.0137	l7tmre_p092r080_20130219_di7m5.img	21.1	21.8	55.3	24.3	1.0	74.7	3.7	16.3
WST002	20130218	147.9563	-29.0134	l7tmre_p092r080_20130219_di7m5.img	19.4	25.0	54.0	32.0	0.3	67.7	3.3	38.3
WST003	20130219	147.4551	-29.8814	l7tmre_p092r081_20130203_di7m5.img	19.4	20.0	58.7	13.0	0.0	87.0	0.0	20.0
WST004	20130219	147.4548	-29.8802	l7tmre_p092r081_20130219_di7m5.img	18.1	8.9	71.2	15.0	1.7	83.3	0.0	0.0
WST005	20130219	147.5149	-29.6954	l7tmre_p092r081_20130203_di7m5.img	28.8	21.6	47.7	28.3	2.0	69.7	0.7	26.3
WST006	20310220	147.4504	-29.6831	l7tmre_p092r081_20130219_di7m5.img	19.6	8.0	70.8	8.0	4.3	87.7	0.0	0.0
WST007	20310220	147.4444	-29.6838	l7tmre_p092r081_20130203_di7m5.img	13.2	20.9	64.2	22.7	2.0	75.3	17.3	1.3
WST008	20130221	147.6743	-29.5314	l7tmre_p092r081_20130203_di7m5.img	20.0	32.7	45.2	27.3	0.3	72.3	0.0	44.3
WST009	20130221	147.6756	-29.5313	l7tmre_p092r081_20130219_di7m5.img	28.1	14.2	55.6	19.0	1.0	80.0	0.0	9.3
WST010	20130304	142.0295	-30.7998	l7tmre_p096r081_20130216_di7m4.img	31.8	5.3	61.3	33.0	3.0	64.0	5.7	0.0
WST011	20130304	141.7461	-30.8019	l7tmre_p096r081_20130216_di7m4.img	37.8	6.8	53.3	46.3	3.7	50.0	2.7	6.0
WST012	20130305	141.5344	-30.1845	l7tmre_p096r081_20130320_di7m4.img	40.4	0.0	58.0	20.0	4.7	75.3	4.0	0.3
WST013	20130305	141.5347	-30.1866	l7tmre_p096r081_20130216_di7m4.img	29.6	1.8	67.1	28.0	5.3	66.7	1.0	0.3
WST014	20130306	141.2073	-31.07	l7tmre_p096r082_20130320_di7m4.img	54.8	5.8	37.2	49.2	5.7	45.2	3.7	0.0
WST015	20130306	141.2015	-31.0671	l7tmre_p096r082_20130216_di7m4.img	38.0	5.3	54.9	29.4	7.4	63.2	7.4	0.0
WST016	20130306	141.1744	-31.085	l7tmre_p096r082_20130216_di7m4.img	23.6	0.0	75.4	13.3	5.0	81.7	0.3	0.0
WST017	20130307	141.7472	-30.8011	l7tmre_p096r081_20130216_di7m4.img	31.4	4.2	62.7	29.3	3.7	67.0	7.7	4.0
WST018	20130307	141.7169	-31.073	l7tmre_p096r082_20130216_di7m4.img	38.9	5.4	53.8	57.7	3.3	39.0	0.0	2.0
WST019	20130307	141.7189	-31.0653	l7tmre_p096r082_20130216_di7m4.img	36.6	8.7	52.9	64.3	4.0	31.7	0.0	13.7

Table 1: Field site attributes and image values for Western CMA

This effect can be clearly seen in Figure 12. In this figure the total green fraction has been calculated by adding the measured green cover from each of ground, mid and over storeys together, and plotting against the image green value giving the blue points. The ground green cover against the image green cover has also been plotted for reference in yellow. It can be seen that the total green fraction has a better fit to the image green fraction than the ground cover green fraction alone. This is due to the contribution of the mid and over storeys to the green signal present for a given pixel.

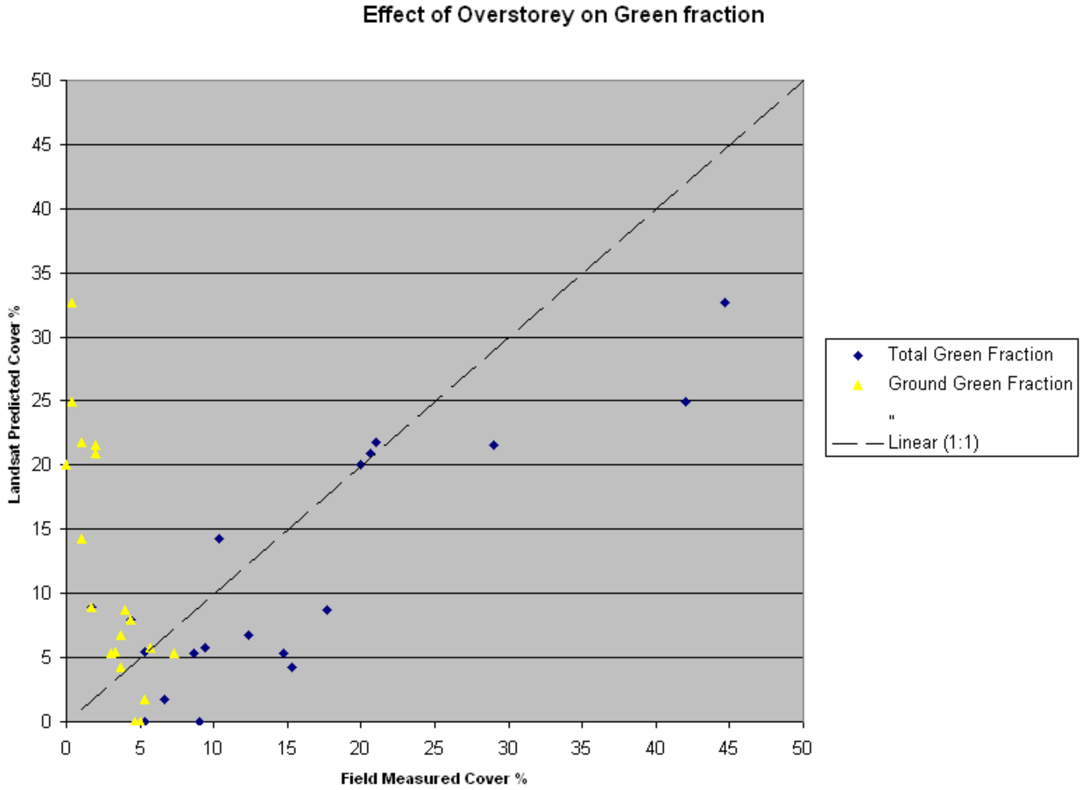


Figure 12: Analysis of Green Fraction for Western CMA sites

The effect of green cover being obscured by a green cover in a higher storey (e.g. green grass under shrubs and trees) has not been compensated for, which potentially leads to an over estimate of green cover in the ground measurement. This can be seen to some degree the plot as the total green cover values plotting below the 1:1 line, as the field measurement can double or triple count green cover for a sample point.

For areas of high tree cover the dii stage (ground cover fractions with high tree cover masked out) is likely to be a better product for ground cover analysis as areas affected by complications introduced by trees are removed from the analysis. As the dii stage is composited from a range of individual summer images, comparison of field sites measured on specific autumn dates to the summer mosaic was impossible.

7 Development of ground cover statistical summaries product requirements

The reporting requirements for ground cover monitoring were discussed at the project meeting in February 2013 in Dubbo. The requirement was for statistical summaries of ground cover at the Rangetype and Socio- Economic System scale across the Western CMA area of operations over the period Summer 2006 to Summer 2012.

7.1 Generation of statistical summaries of ground cover data

The predictive accuracy of the ground cover using the fractional cover products is highest in areas with sparse or no woody vegetation. In areas with dense woody vegetation, the ground cover under the trees and shrubs cannot be predicted with a high level of confidence. Hence, a woody mask based on areas greater than or equal to 7% FPC in the 2008 Landsat woody extent and FPC product (Danaher, 2011) was used to mask out woody areas when generating statistical summaries of the ground cover data. This mask was applied to the summer catchment wide mosaics described previously to create “dii” stage mosaics which were then used for the calculation of fractional cover summary statistics.

Reporting of results can be performed using a variety of boundaries. For the purposes of this project it was agreed by CMA staff that the intersection of the socio-economic systems and major range type was a suitable set of reporting regions. This meant that 10 major range types and 5 SES regions were intersected, creating 34 distinct SES/range type pairs. The ground cover data was summarised for the entire Western CMA area of operations and for each SES/range type region using the masks outlined above. Figure 13 shows the map of the range type/SES regions used to summarise the ground cover data.

The full statistical summary containing mean and percentile ground cover for the each SES/range type region is provided as an Excel spreadsheet *west_cma_cover_stats.xls*

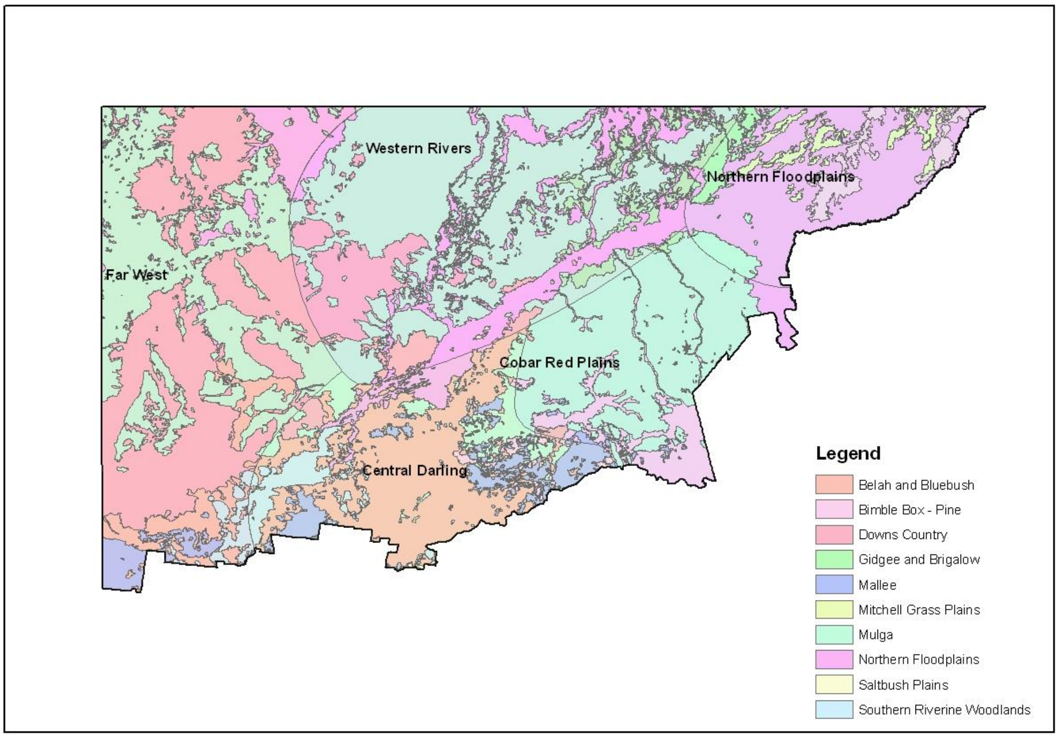


Figure 13: Sub-catchment boundaries used for statistical summary data overlaid on Landsat image mosaic

7.2 Fractional cover statistical summary for the Western Catchment

The catchment wide fractional cover estimates over the 2006–2013 summer season are shown in Figure 14.

This graph shows the total catchment cover for each summer season along with the contribution of both green and dead fraction to the total cover. The total cover shown is based on the bare fraction e.g. 100 - bare %. In addition to total cover, the 5th and 95th percentiles for each cover fraction are also shown as dashed lines. It is important to consider the range of cover not just the mean cover. For example, the mean total cover is always above 45% but there are some areas in the catchment where mean total cover is less than 30%.

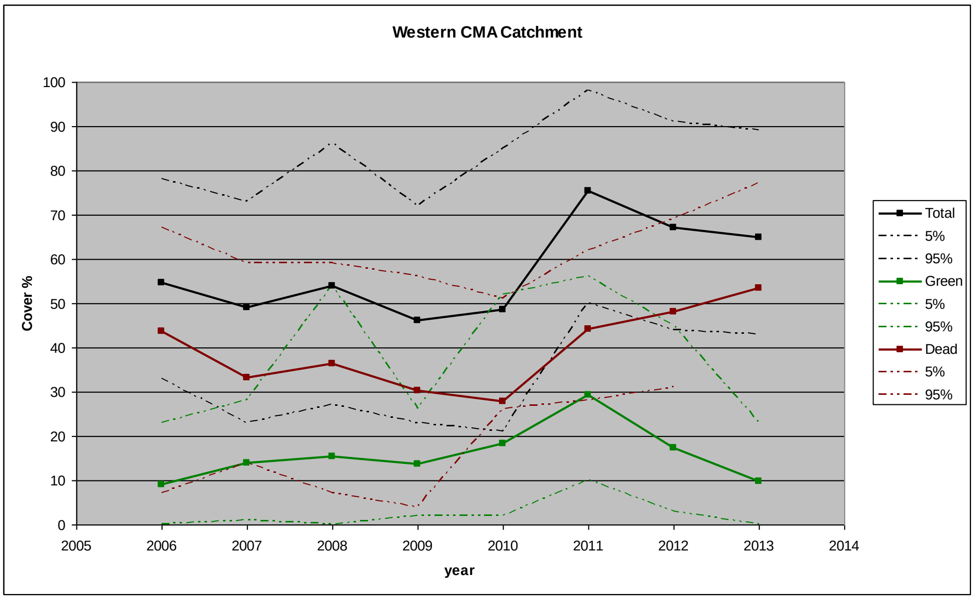


Figure 14: Graph of ground cover Western CMA for the 2006–2013 period showing mean cover and 5, 50 and 95 percentile cover. Areas with woody vegetation greater or equal to 7% FPC were excluded

The change in cover though time on a catchment wide basis is a significant result and should contribute to decision making processes within the Western CMA. In addition to the catchment wide statistics, further information on each of the range type and SES region combination has also been generated and is available from the accompanying excel spreadsheet. Figure 15 below is an example of the fractional cover history for the Mitchell Grass range type in the Northern Floodplain SES region and shows a distinctly different trend to that of the entire catchment.

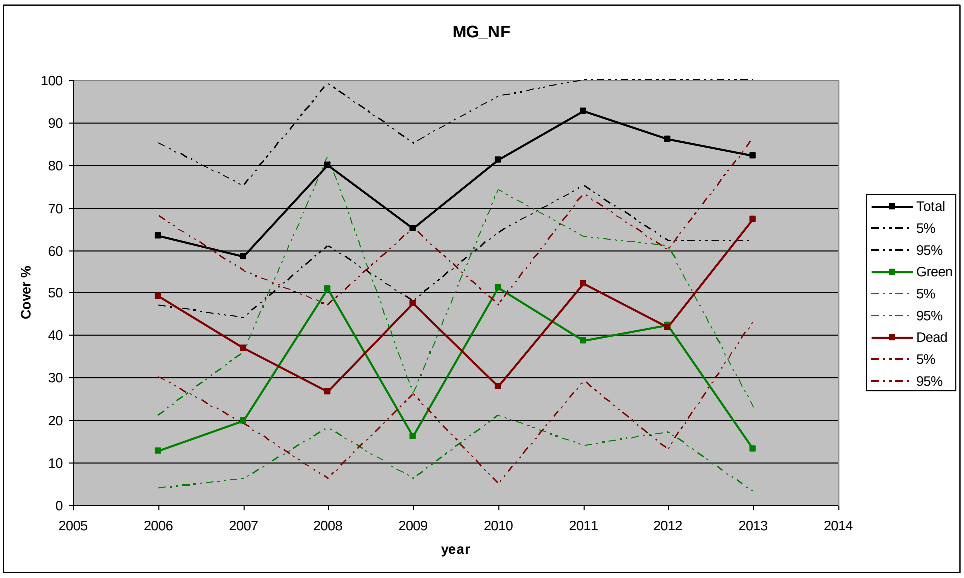


Figure 15: Fractional cover for Mitchell Grass range type of the Northern Floodplains SES region

8 Recommendations for ongoing monitoring

Below are recommendations for ongoing monitoring in the Western CMA. We divide the recommendations into two areas. The first section discusses those projects that will deliver results in a short to medium time frame. The second section discusses projects that require further research to develop new image-based products, and will deliver results in a medium to long time frame. A third section discusses other work being undertaken by OEH that we think are of interest to the Western CMA.

8.1 Short to medium term activities

1. Ongoing monitoring of selected field sites. OEH and its partners have a large network of field monitoring sites that relate ground cover to satellite imagery. This provides us with an excellent picture of how well the products perform across the landscape. However, there are very few sites at which frequent, repeated monitoring takes place. Therefore, there is less knowledge of how a change in cover as indicated by the imagery, relates to on-ground change. It is recommended that support be provided to establish long-term monitoring sites.

2. Reporting on a quarterly basis. The processing systems to produce seasonal cover images are well advanced. These include automated (but not perfect) cloud-masking procedures and statistically robust compositing methods (based on the medoid). The production of seasonal cover products will therefore be mostly automated. This will allow monitoring and reporting on a quarterly basis. We recommend further support be provided to develop a reporting system based on seasonal cover products. For example, every quarter, the western CMA is provided with a pdf report, via email. This report contains an image of the latest cover fractions for the catchment, and a graph showing how the ground cover across the catchment and within specified regions are tracking over time. The report can be tailored to suit the Western CMA's needs.

3. Comparing ground cover within target areas to a regional context. The ground cover trends, presented as graphs in this document and the accompanying spreadsheet, can be used to examine how each region of interest is tracking against the catchment. There is potential to apply similar analyses to specified paddocks, properties or other regions of interest. Comparisons can be made to the ground cover in surrounding paddocks, e.g. within

a 50 km radius, that are on the same land type, rather than making comparisons to the entire catchment. This will give a better indicator of how well a paddock is performing when compared to similar paddocks, which may be an indicator of the paddock's condition. The seasonal cover products can be used for analysis, and the results delivered within a reporting system framework as outlined above.

4. Other time-series statistics based on seasonal cover products. The seasonal cover products can be used as the baseline from which other statistical products can be generated. Long-term seasonal average and anomaly products, which show how the ground cover within each pixel is tracking against its long-term average, can be produced. The data can also be used to analyse trends. For example, 5-year, 10-year trends showing increases or decreases in cover can be produced. These could be compared to the regional context and reported within a reporting system framework as outlined above.

8.2 Medium to long term activities

Production of regular seasonal cover imagery provides a rich source of data from which other products can be derived, for monitoring, evaluation and reporting. Here are some suggestions:

1. Investigate the use of the seasonal cover products for monitoring woody regrowth, thickening and encroachment.
2. Use the seasonal cover products for deriving landscape function metrics, such as the Landscape Leakiness Index (Ludwing et.al. 2002), and relating those to on-ground observations.
3. Investigate the use of the seasonal cover products for identification of areas within the CMA that exhibit particular trends through time. For example areas in decline or long term stable areas

8.3 Other activities

1. Landsat 8 was successfully launched on February 11 2013. OEH, in conjunction with its JRSRP partners, plan to produce fractional cover products using Landsat 8 data. This will ensure an ongoing archive of fractional and seasonal cover products from the Landsat sensors. The archive will span more than 30 years.

2. OEH are currently engaged in a project with the Australia Collaborative Rangeland Information System. The project aims to report on the condition of ground cover in the NSW rangelands, by separating grazing and rainfall effects on ground cover, using the Dynamic Reference Cover Method (Bastin et. al. 2012). These results will be of interest to the Western CMA.

9 Conclusion

The Landsat fractional cover method is now well established and the model well supported by site measurements in Western CMA and in many other locations in NSW and QLD. It is likely that this method will be used by many agencies for monitoring ground cover. It is recommended that the Western CMA use the Landsat fractional cover product for ongoing monitoring of ground cover particularly in relation to identification of suitable catchment targets in the Catchment Action Plan review process.

This project has seen the completion of the fractional-cover model calibration for use in the WCMA and some applications of the products have been demonstrated. Although the fractional cover model is now developed and validated it would be useful to maintain a small field monitoring program with the aim of acquiring site repeat measurements covering a few existing sites under different seasonal conditions.

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- Neil Flood for developing and supporting the software systems that enables the largely automated processing of the Landsat imagery.

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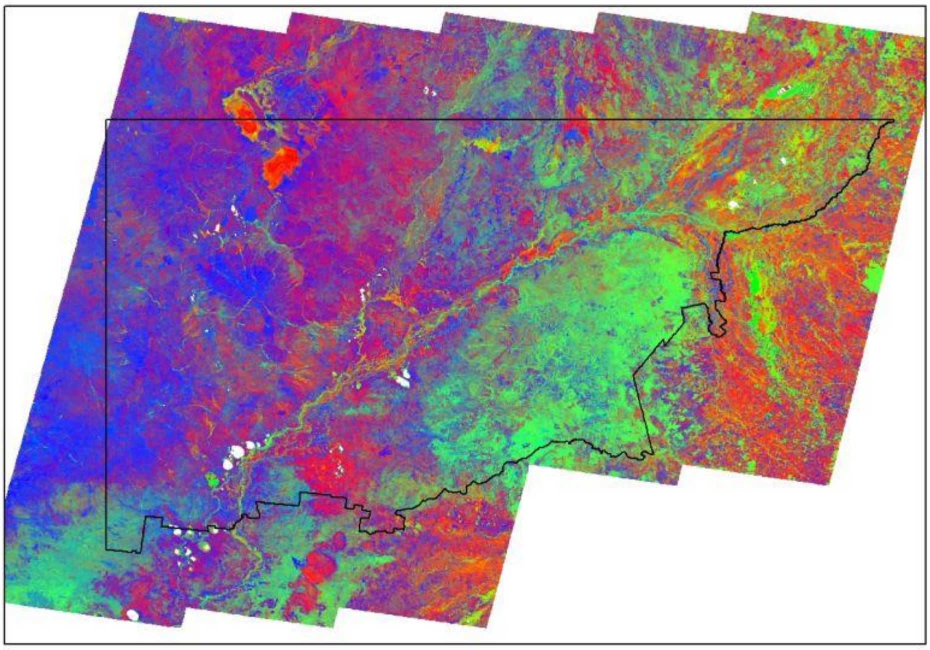
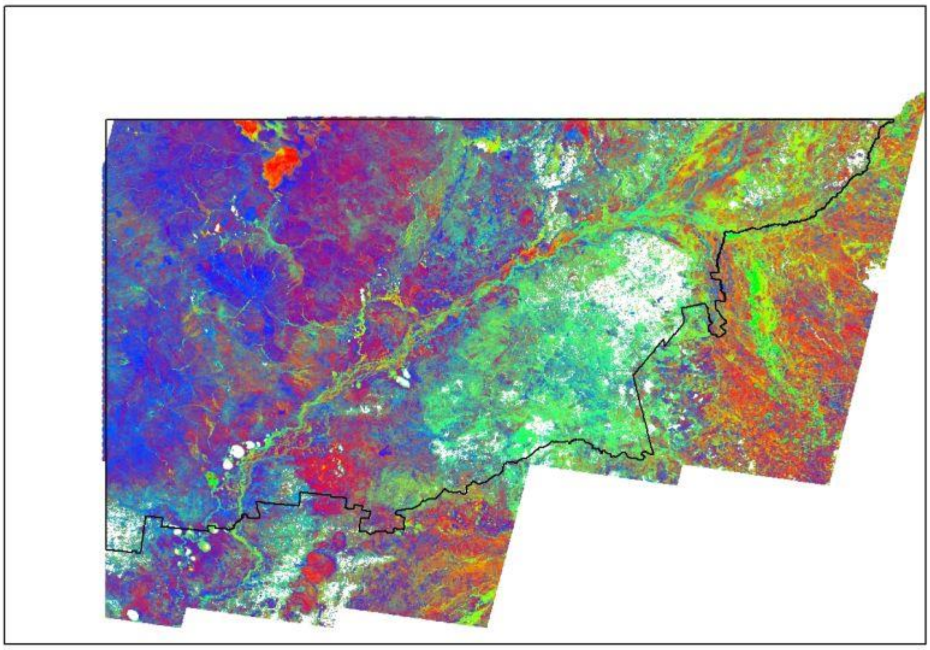
Appendix 1 - List of image stages with examples:

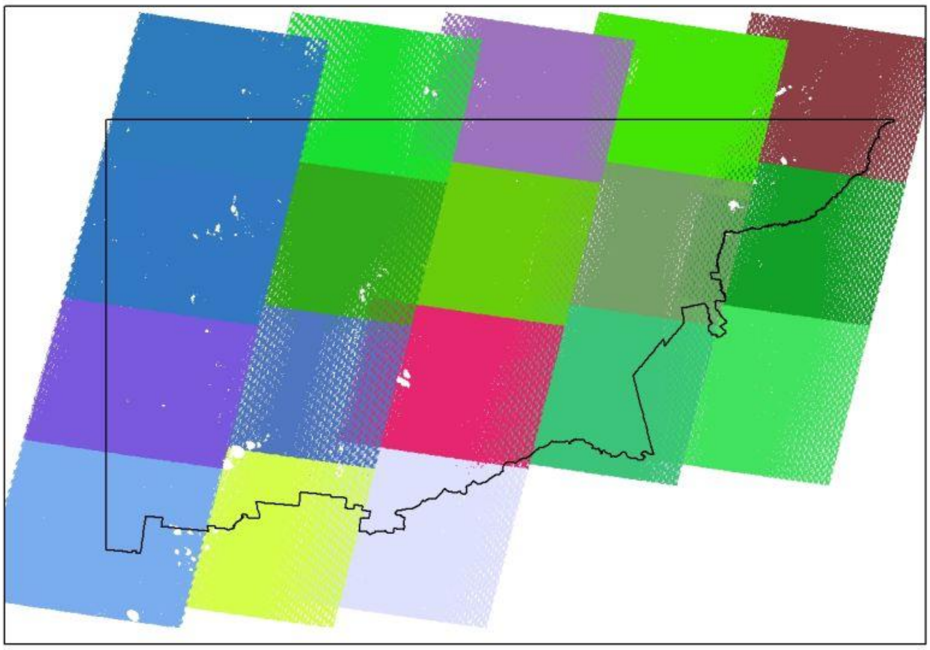
die = masked fractional cover with water, topo, cloud and shadow masks applied. Five layers: 1= bare, 2 = green, 3 = non-green, 4 = model residual, 5 = sum of fractions. Image shows bare (Red), green (Green) and dead (Blue).



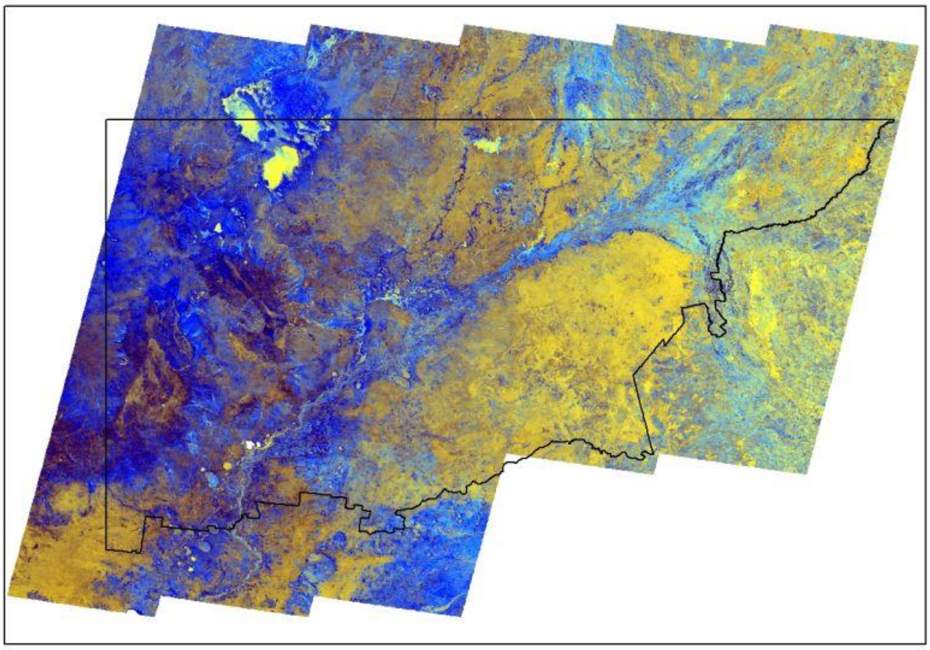
dii =die masked with high FPC areas removed.
Five layers: 1= bare, 2 = green, 3 = non-green, 4 = model residual, 5 = sum of fractions. Image shows bare (Red), green (Green) and dead (Blue).



diz = pointer image.
Details the image of origin for every pixel in a catchment mosaic.1 Layer

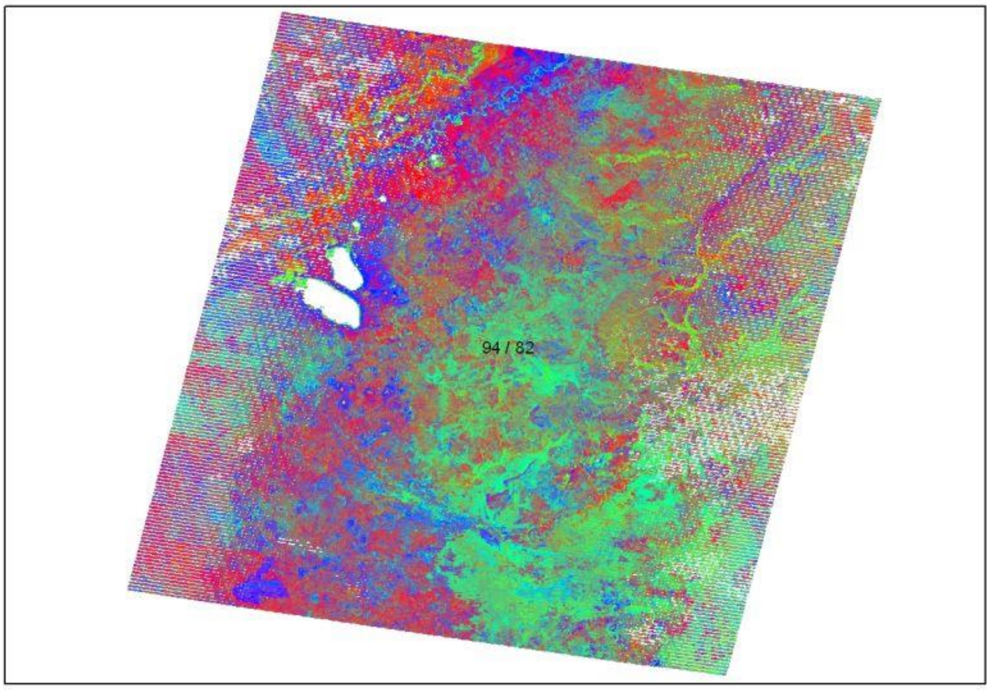


dip = percentile mosaic
5 layers 1= 5th Percentile, 2= 50th Percentile, 3= 95th Percentile, 4= Standard Deviation, 5= Number of Observations. Example depicts bands 1 (Red), 2 (Green), 4 Blue)



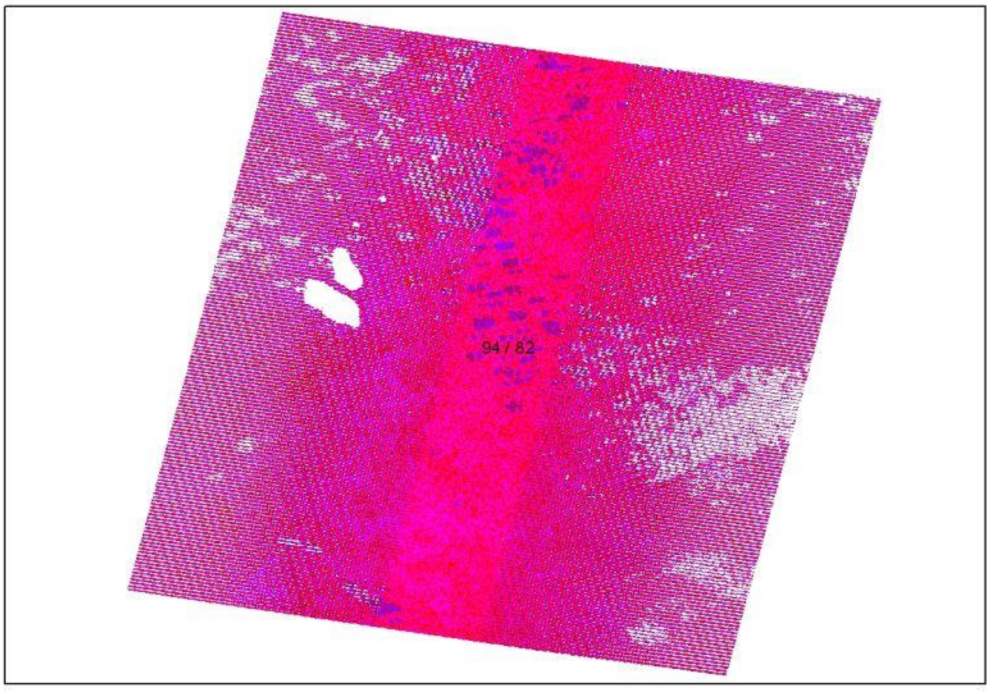
dij = Seasonal fractional cover.

Five layers: 1= bare, 2 = green, 3 = non-green, 4 = model residual, 5 = sum of fractions. Image shows bare (Red), green (Green) and dead (Blue).



dik= pointer image.

Details the image of origin for each pixel in the seasonal fractional cover image. 2 Layers. 1= date chosen, per-pixel. 2= number of dates from which the selection was made.



Appendix 2 - Supplied images:

Catchment percentile ground cover mosaic
lztmre_cwestern06_m200601201301_dipl0.img

Catchment masked (cloud, shadow, and water) fractional cover mosaics for each summer season from 2006 to 2013.
lztmre_cwestern06_m200512200602_diel0.img
lztmre_cwestern06_m200612200702_diel0.img
lztmre_cwestern06_m200712200802_diel0.img
lztmre_cwestern06_m200812200902_diel0.img
lztmre_cwestern06_m200912201002_diel0.img
lztmre_cwestern06_m201012201102_diel0.img
lztmre_cwestern06_m201112201202_diel0.img
lztmre_cwestern06_m201212201302_diel0.img

Catchment masked (cloud, shadow, water, and woody) fractional cover mosaics for each summer season from 2006 to 2013.
lztmre_cwestern06_m200512200602_diil0.img
lztmre_cwestern06_m200612200702_diil0.img
lztmre_cwestern06_m200712200802_diil0.img
lztmre_cwestern06_m200812200902_diil0.img
lztmre_cwestern06_m200912201002_diil0.img
lztmre_cwestern06_m201012201102_diil0.img
lztmre_cwestern06_m201112201202_diil0.img
lztmre_cwestern06_m201212201302_diil0.img

Catchment image pointer mosaics for each summer season from 2006 to 2013.
lztmre_cwestern06_m200512200602_dizl0.img
lztmre_cwestern06_m200612200702_dizl0.img
lztmre_cwestern06_m200712200802_dizl0.img
lztmre_cwestern06_m200812200902_dizl0.img
lztmre_cwestern06_m200912201002_dizl0.img
lztmre_cwestern06_m201012201102_dizl0.img
lztmre_cwestern06_m201112201202_dizl0.img
lztmre_cwestern06_m201212201302_dizl0.img

Seasonal fractional cover composites for three scenes. Note that the corresponding pointer files are also included. They have the stage code, 'dik'.
Insufficient images were available for winter 2008 p093r081 to compute the seasonal fractional cover. See the README.txt file in p093r081 for how this file was created.
p093r081
lztmre_p093r081_m200512200602_dijm5.img
lztmre_p093r081_m200603200605_dijm5.img
lztmre_p093r081_m200606200608_dijm5.img
lztmre_p093r081_m200609200611_dijm5.img
lztmre_p093r081_m200611200702_dijm5.img
lztmre_p093r081_m200703200705_dijm5.img
lztmre_p093r081_m200706200708_dijm5.img
lztmre_p093r081_m200709200711_dijm5.img
lztmre_p093r081_m200712200802_dijm5.img
lztmre_p093r081_m200803200805_dijm5.img
lztmre_p093r081_m200809200811_dijm5.img
lztmre_p093r081_m200812200902_dijm5.img
lztmre_p093r081_m200903200905_dijm5.img
lztmre_p093r081_m200906200908_dijm5.img

lztmre_p093r081_m200909200911_dijm5.img
lztmre_p093r081_m200912201002_dijm5.img
lztmre_p093r081_m201003201005_dijm5.img
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lztmre_p093r081_m201009201011_dijm5.img
lztmre_p093r081_m201012201102_dijm5.img
lztmre_p093r081_m201103201105_dijm5.img
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lztmre_p093r081_m201206201208_dijm5.img
lztmre_p093r081_m201209201211_dijm5.img
lztmre_p093r081_m201212201302_dijm5.img
l7tmre_p093r081_m200806200808_dijm5.img

p094r082

lztmre_p094r082_m200512200602_dijm5.img
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lztmre_p094r082_m200703200705_dijm5.img
lztmre_p094r082_m200706200708_dijm5.img
lztmre_p094r082_m200709200711_dijm5.img
lztmre_p094r082_m200712200802_dijm5.img
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lztmre_p094r082_m200806200808_dijm5.img
lztmre_p094r082_m200809200811_dijm5.img
lztmre_p094r082_m200812200902_dijm5.img
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lztmre_p094r082_m201203201205_dijm5.img
lztmre_p094r082_m201206201208_dijm5.img
lztmre_p094r082_m201209201211_dijm5.img
lztmre_p094r082_m201212201302_dijm5.img

p096r082

lztmre_p096r082_m200512200602_dijm4.img
lztmre_p096r082_m200603200605_dijm4.img
lztmre_p096r082_m200606200608_dijm4.img
lztmre_p096r082_m200609200611_dijm4.img
lztmre_p096r082_m200611200702_dijm4.img
lztmre_p096r082_m200703200705_dijm4.img
lztmre_p096r082_m200706200708_dijm4.img
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lztmre_p096r082_m200809200811_dijm4.img
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lztmre_p096r082_m200912201002_dijm4.img
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lztmre_p096r082_m201006201008_dijm4.img
lztmre_p096r082_m201009201011_dijm4.img
lztmre_p096r082_m201012201102_dijm4.img
lztmre_p096r082_m201103201105_dijm4.img
lztmre_p096r082_m201106201108_dijm4.img
lztmre_p096r082_m201109201111_dijm4.img
lztmre_p096r082_m201112201102_dijm4.img
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lztmre_p096r082_m201206201208_dijm4.img
lztmre_p096r082_m201209201211_dijm4.img
lztmre_p096r082_m201212201302_dijm4.img

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