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Cover image: Chenopod shrublands, southern rangelands, South Australia (Rob Lesslie, ABARES).
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Summary

Ground cover is the vegetation, biological crusts and stones in contact with the soil surface. It has a significant impact on the amount of soil redistributed or lost through wind and water erosion, on the biomass which contributes to soil carbon levels and the ability of vegetation to respond to rain after drought. Ground cover can be monitored directly through remote sensing.

A workshop was held in Canberra (23–24 November 2009) to reach consensus on a nationally coordinated approach to ground cover mapping. Different approaches were presented for estimating ground cover using remote sensing. The issues surrounding validation of such remotely sensed products were also discussed. Discussions were guided by the user specifications for this product.

A first step in this coordinated approach was the establishment of four working groups from the workshop participants. The working groups are:

1 fractional cover mapping operational for the nation—using the Moderate Resolution Imaging Spectroradiometer (MODIS) at 500-metre spatial resolution as a 16-day composite
2 upscaling—from field data to high/medium resolution, small extent imagery to low resolution, large area imagery
3 field data collection—for validation of fractional cover derived from remote sensing
4 monitoring land management practices with remote sensing.

Collectively, the four working groups will advise on the delivery of a validated fractional cover product for Australia. This product will be used:

• to monitor ground cover levels
• as a key input to wind and water erosion modelling to predict rates of soil loss
• to monitor the impact of different management practices on ground cover levels and soil erosion risk.

The method of Guerschman et al. (2009) has been selected as the approach to implement nationally, with initial focus on making this MODIS-based fractional cover product operational. Essential to the use of this product is the accuracy of its ground cover estimates. The collection of field measurements and the use of upscaling techniques will underpin the validation and improvement of this fractional cover product.

The working groups documented the workshop discussion and have recommended a way forward. The effort required to implement the suggested tasks has been estimated and will be used to inform the development of a project plan. Progress on the project is available on the Caring for our Country website: http://www.nrm.gov.au/publications/factsheets/ground-cover-factsheet.html.
Acronyms and initialisms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tr>
<td>ABARES</td>
<td>Australian Bureau of Agricultural and Resource Economics and Sciences</td>
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<td>ABS</td>
<td>Australian Bureau of Statistics</td>
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<tr>
<td>ACLUMP</td>
<td>Australian Collaborative Land Use and Management Program</td>
</tr>
<tr>
<td>ACRIS</td>
<td>Australian Collaborative Rangeland Information System</td>
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<td>ALUM</td>
<td>Australian Land Use and Management (Classification)</td>
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<tr>
<td>ARM</td>
<td>Agricultural Resource Management (Survey)</td>
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<tr>
<td>AVHRR</td>
<td>Advanced Very High Resolution Radiometer</td>
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<tr>
<td>BG / BS</td>
<td>Bare ground / bare soil</td>
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<td>BRDF</td>
<td>Bidirectional reflectance distribution function</td>
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<tr>
<td>BRS</td>
<td>Bureau of Rural Sciences</td>
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<tr>
<td>CAI</td>
<td>Cellulose absorption index</td>
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<tr>
<td>CEMSYS</td>
<td>Computational Environmental Management System</td>
</tr>
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<td>CEO</td>
<td>Committee on Earth Observation Satellites</td>
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<td>CSIRO Mathematics, Informatics and Statistics</td>
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<tr>
<td>CLW</td>
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<td>Catchment Management Authority</td>
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<td>CSIRO</td>
<td>Commonwealth Scientific and Industrial Research Organisation</td>
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<tr>
<td>DAFF</td>
<td>Department of Agriculture, Fisheries and Forestry (Australian Government)</td>
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<tr>
<td>DECCW</td>
<td>Department of Environment, Climate Change and Water (New South Wales)</td>
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<tr>
<td>DERM</td>
<td>Department of Environment and Resource Management (Queensland)</td>
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<tr>
<td>EVI</td>
<td>Enhanced vegetation index</td>
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<td>GCI</td>
<td>Ground cover index</td>
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<td>GA</td>
<td>Geoscience Australia</td>
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<td>GRDC</td>
<td>Grains Research and Development Corporation</td>
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<td>IDL</td>
<td>Interactive Data Language</td>
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<td>LAI</td>
<td>Leaf area index</td>
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<td>LUMIS</td>
<td>Land Use and Management Information System</td>
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<tr>
<td>MCAS-S</td>
<td>Multi-Criteria Analysis Shell for Spatial decision support</td>
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<tr>
<td>MODIS</td>
<td>Moderate Resolution Imaging Spectroradiometer</td>
</tr>
<tr>
<td>NBAR</td>
<td>Nadir (directly below sensor) BRDF-Adjusted Reflectance</td>
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<td>NCLUMI</td>
<td>National Committee for Land Use and Management Information</td>
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<td>NCST</td>
<td>National Committee on Soil and Terrain</td>
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<td>NDVI</td>
<td>Normalized Difference Vegetation Index</td>
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<td>Natural resource management</td>
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<td>National Land and Water Resources Audit</td>
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<td>Non-photosynthetic vegetation</td>
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<td>PV</td>
<td>Photosynthetic vegetation</td>
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<tr>
<td>RUSLE</td>
<td>Revised Universal Soil Loss Equation</td>
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<tr>
<td>SLATS</td>
<td>Statewide Landcover And Trees Study (Queensland)</td>
</tr>
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<td>TERN</td>
<td>Terrestrial Ecosystem Research Network</td>
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<tr>
<td>USGS</td>
<td>United States Geological Survey</td>
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Introduction

A target of the Australian Government’s Caring for our Country program is to improve the condition of the soil resource through adoption of better land management practices. Ground cover is a good indicator of management and its impact on soil condition (figure 1). Through the Australian Bureau of Statistics’ Agricultural Resource Management (ARM) Survey, data are collected on ground cover management such as tillage and stubble practices, how ground cover levels are monitored and minimum ground cover level targets for grazed paddocks (for example, map 1). These data are used for intermediate outcome reporting for Caring for our Country on sustainable practices. A suitable remotely sensed product of ground cover would enable ground cover levels to be directly monitored consistently for Australia over months, seasons and years. Such a product would give trends in ground cover levels complementing the ARM Survey and as an input to wind and water erosion, soil carbon and acidification models enabling forecasting. Ideally, this remotely sensed product would distinguish between the living and dry/dead vegetation and bare soil—a fractional ground cover product.

A workshop was held in Canberra (23–24 November 2009) to reach consensus on a nationally coordinated approach to ground cover mapping. Appendix A lists the presentations given to inform discussion on different methods and validation of such remotely sensed products. Workshop participants represented potential collaborators and users of a remotely sensed ground cover product (Appendix B). With limited resourcing, a collaborative approach will be important for achieving success. The adopted approach and delivered national product must thus seek to meet partners’ needs—those of the Australian Government, state and territory governments and others.

Specifications of a remotely sensed product for monitoring ground cover nationally were provided to workshop participants to focus discussions. These specifications are given in Appendix C. In summary, a national fractional cover product is required at monthly intervals (at 500 to 1000-metre resolution) supported by a yearly woody layer and a yearly or seasonal medium (30-metre) resolution layer. A high priority to validate the selected remotely sensed product/s is a network of reference sites where the method used to measure fractional cover is sensor-independent. A staged approach is required to deliver a national remotely sensed ground cover product, considering user needs, image acquisition and storage costs and availability of existing suitable or adaptable methodologies.
The importance of ground cover in minimising (a) water erosion and (b) wind erosion

![Graphs showing the relationship between ground cover and soil erosion]

Note: Threshold levels are indicated as green for low risk, orange for medium risk and red for high risk of soil erosion.
Source: Barson and Leys, workshop presentation.

Results from the 2007–08 ARM Survey showing graziers with a minimum ground cover target

![Map of Australia showing the distribution of graziers with ground cover targets]

Note: Sixty-nine per cent of graziers monitored ground cover in 2007–08. Fifty-seven per cent of these graziers had a minimum ground cover target of 40 per cent to more than 80 per cent (ABS 2009).
Source: Barson and Leys, workshop presentation.
Land cover is the physical surface of the earth, including various combinations of vegetation types, soils, exposed rocks and water bodies. Land cover classes may be discriminated by characteristic patterns using remote sensing. Land cover is distinct from land use. Land use is how humans use the land, for example for urban and agricultural land uses.

Fractional cover is the fraction of an area (usually a pixel for the purposes of remote sensing) that is covered by a specific cover type such as green or photosynthetic vegetation, non-photosynthetic vegetation (that is, stubble, senescent herbage and leaf litter) or bare soil/rock. Areas that have been burnt resulting in ash/blackened soil are considered as a bare soil cover type.

Ground cover is the vegetation (living and dead), biological crusts and stone that is in contact with the soil surface. Non-woody ground cover such as crops, grass, forbs and chenopod-type shrubs may change monthly, making this component a good indicator of land management performance (Leys et al. 2009). Ground cover is a sub-component of land cover and, from a remote sensing perspective, is the fractional cover of the non-woody understorey.
Box 1 defines ground cover and fractional cover in terms of remote sensing. A remotely sensed fractional cover product considers all vegetative cover—woody and non-woody at the different strata—ground, mid, upper and emergent (as defined in NCST 2009). To achieve a ground cover product, the fractional cover for non-woody vegetation within the ground strata (usually less than 2 metres tall) is of interest only. This requires a woody cover layer to mask the fractional cover product in those areas under woodlands and forests where it is difficult to extract ground cover. Such a woody layer is produced annually by some states for reporting of tree clearing and nationally for the National Carbon Accounting System by the Department of Climate Change and Energy Efficiency. Queensland Department of Environment and Resource Management (DERM) has recently tried unmixing Landsat pixels to provide cover estimates under canopies; however, this requires validation and further research.

**Box 2  Characterisation of satellite remote sensing systems**

Different remote sensing satellite systems have diverse spatial, temporal and spectral resolutions.

**Spatial resolution** specifies the pixel size of satellite images covering the earth’s surface.
- High spatial resolution: 0.6–4 metres
- Medium spatial resolution: 4–30 metres (for example, Landsat)
- Low spatial resolution: 30 – >1000 metres (for example, MODIS)

**Temporal resolution** specifies the revisiting frequency of a satellite sensor for a specific location.
- High temporal resolution: < 24 hours – 3 days (for example, MODIS)
- Medium temporal resolution: 4–16 days (for example, Landsat)
- Low spatial resolution: > 16 days

**Spectral resolution** specifies the number of spectral bands in which the sensor can collect reflected radiance. Another important aspect of spectral resolution is the position of the bands in the electromagnetic spectrum.
- High spectral resolution: 16–220 bands
- Medium spectral resolution: 3–15 bands (for example, Landsat and MODIS for bands related to land properties)
- Low spectral resolution: < 3 bands

Owing to technical constraints, satellite remote sensing systems can only offer a high spatial resolution with a medium or low spectral resolution, and vice versa. For different applications it is necessary to find compromises between the different resolutions or to use alternative methods of data acquisition.

Photosynthetic and non-photosynthetic vegetation and bare soil have different spectral responses. These spectral responses can be used to select these components using remote sensing. Figure 2 illustrates how the algorithm of Guerschman et al. (2009) can extract the different fractional components. The ratio of MODIS band 7 to band 6 correlates negatively with the cellulose absorption index (CAI) and can be used with the Normalised Difference Vegetation Index (NDVI) to resolve the vegetation fractional cover with MODIS. The University of Adelaide also uses MODIS bands 6 and 7 to predict the cover rating from South Australia’s windscreen surveys. Both methods require independent field-based fractional cover data for calibration and validation of the derived MODIS-based products.

The algorithm of Guerschman et al. (2009) was developed for the northern savannas of Australia and applied nationally. The data are available as a 16-day composite on an 8-day phased production at 500-metre spatial resolution from 2000 onward (http://www-data.wron.csiro.au/remotesensing/MODIS/products/Guerschman_etal_RSE2009/; map 2).

The University of Adelaide’s index has been developed for South Australia’s agricultural lands and is not currently available nationally or publicly. Future developments include the use of fractional cover indices from relative spectral mixture analysis (Clarke et al. 2010).

Geoscience Australia (GA) and ABARES have developed a 250-metre Dynamic Land Cover Map (Lymburner et al. 2010) for Australia, which is due for public release in early 2011. This characterises the enhanced vegetation index time series to obtain statistics, phenology and seasonality factors on photosynthetic vegetation. GA aims to link the fractional vegetation cover product of Guerschman et al. (2009) to the Dynamic Land Cover Map to enable interpretation of trends in vegetative cover (separating photosynthetic and non-photosynthetic vegetation) under different land cover types.

DERM uses Landsat (and MODIS) to provide an annual ground cover index for all of Queensland (map 3). A Landsat-based (30-metre) woody vegetation cover product is also produced annually. DERM is moving toward a Landsat ground cover product which separates...
the three fractional components (photosynthetic vegetation, non-photosynthetic vegetation and bare soil), and is currently considering the accuracy and operational efficiencies of three approaches: (i) a regression-based bare ground prediction, (ii) multiple logistic regression algorithms and (iii) a spectral unmixing approach (Schmidt et al. 2010a). With free access to the United States Geological Survey Landsat image archive back to 2000, Queensland is acquiring imagery to enable time series analysis (for example, Scarth et al. 2010) within years (of up to 20 images per year) as well as their current annual end of dry season time series back to before 2000.

Airborne hyperspectral data are useful for mapping non-photosynthetic vegetation and the types of bare soil/rock, as they are not influenced by variation in soil moisture as multispectral sensors such as Landsat and MODIS are. Airborne hyperspectral data are available now but at a cost of approximately $15 million for a 15-metre baseline map of Australia. From 2013, hyperspectral soil products will become routinely accessible to Australia. CSIRO Exploration & Mining’s 10-year vision is web-accessible hyperspectral mineral maps of the Australian continent for baseline mapping and monitoring.

Map 2 Mean fractional vegetation cover for 2000–2009

Note: PV = photosynthetic vegetation, NPV = non-photosynthetic vegetation, BS = bare soil.
Source: Guerschman, workshop presentation.
Points to consider for monitoring ground cover using remote sensing are:

- climate is a major cover driver
- the spatial arrangement of cover—often linked to management factors— is lost with increasing pixel size
- soil moisture has an effect on remotely sensed ground cover estimates—particularly multispectral (that is, Landsat and MODIS) estimates of non-photosynthetic vegetation versus bare soil
- atmospheric correction is essential for time series remotely sensed data
- remotely sensed estimates need to be validated with accurate on-ground measurement.

Box 2 summarises how different remote sensing systems are characterised by their spatial, temporal and spectral resolutions, and indicates where the current options (Landsat and MODIS) used for large extent monitoring of ground cover align.

Note: At low (< 40 per cent) ground cover levels information is lost at the 500-metre spatial resolution of MODIS.
Source: Schmidt, workshop presentation.
A remotely sensed fractional ground cover product requires field data to validate the reliability of the product. Various methods are available to collect fractional cover in the field and the accuracy of these methods can and should be assessed. For example, the methods used for grassland curing assessments (that is, the non-photosynthetic vegetation fraction) by the Bushfire Cooperative Research Centre have an accuracy of $\pm 10$ per cent for the Levy Rod method and $\pm 20$ per cent for visual estimates. DERM uses a modified discrete point transect sampling method in their SLATS program (Scarth et al. 2006; Schmidt et al. 2010b) (see figure 4). Automated in situ sensors are also another option for collecting multi-spectral data that can be converted to the three fractional ground cover components.

The Terrestrial Ecosystem Research Network (TERN) is currently establishing a national network of sites for calibration and validation of remotely sensed products supported by its AusCover nodes. Measurements proposed for these sites are:

- canopy multispectral reflectance (nadir or bidirectional)
- leaf spectra (reflectance and transmittance)
- background nadir spectral reflectance (soil and litter)
- fraction of areal vegetation cover
- vegetation crown allometry (height, width, gap)
- phenology (green-up, mature, and senescent stages)
- vegetation composition (either by species or structural type)
- moisture status
- fraction of non-photosynthesising vegetation
- meteorological data.

Collaboration with the TERN initiative will provide access to high spectral reflectance measurements at known sites and, potentially, the required measurements for validating the selected remotely sensed ground cover product. Agreement on standards for measurements at sites will be important for effective linkage between the TERN and this national ground cover project.

TERN will draw on lessons learnt from international validation programs and encourage the use of:

- representative sites
- homogenous or constantly mixed and large (preferably at least 5 kilometres by 5 kilometres) sites
• a hierarchy from highly instrumented supersites to networks of spatially extensive higher order plots
• high spatial resolution images to bridge to coarser resolution images
• autonomous highly instrumented supersites for calibration and validation.

Box 4 provides internationally recognised definitions for calibration and validation.

Some initial validation of the Guerschman et al. (2010) MODIS-based fractional cover product have been undertaken by Schmidt et al. (2010b) and G Bastin ([CSIRO] 2009, pers. comm., September). Analysis of the algorithm’s performance using the flag classes (see map 4) also indicates where the product is currently working and where improvement is required. These types of analyses can assist with establishing sites for calibrating, validating and ultimately improving the selected remotely sensed product to provide ground cover estimates of known reliability.
To coordinate national delivery of ground cover mapping, four working groups were established from the workshop participants. The working groups are:

1. fractional cover mapping operational for the nation—initially using MODIS
2. upscaling—from field data to high/medium resolution, small extent imagery to low resolution, large area imagery
3. field data collection—for validation of fractional cover derived from remote sensing
4. monitoring land management practices with remote sensing.

Collectively, the four working groups will advise on the delivery of a validated fractional cover product for Australia. Figure 3 illustrates the interconnections between the four working groups. Appendix B shows the membership to each of the working groups by workshop participants.
The overarching objectives of the working groups are:

1. validation of an operational fractional cover product
2. ongoing improvement of this product
3. analysis of ground cover estimates from this product.

Each working group's strategy will have as its priority an operational product available in 2010, with ongoing validation and improvement of that product over the term of Caring for our Country (2010–2013). The data collected for the current product validation ideally should be non-sensor specific to allow for production of a finer resolution product when feasible. This should also apply to the algorithms used in upscaling and production of the fractional cover.

The working groups will seek to be actively involved in the progress of related activities under the Terrestrial Ecosystem Research Network (TERN) AusCover (that is, related to calibration and validation of their land products) and identify potential opportunities for co-investment.

**Working group 1: Fractional cover mapping operational for the nation**

The purpose of working group 1 is to make remotely sensed fractional cover products for Australia operational. The initial focus will be the MODIS-based fractional cover product of Guerschman et al. (2009). This working group will seek to improve the existing product by:

- establishing where the existing algorithm does and does not work to inform stratification for locating sites to obtain field data
- using field data to further train the algorithm and validate the product
- revising the Interactive Data Language (IDL) algorithm.

**Working group 2: Upscaling**

The purpose of working group 2 is to develop a strategy for upscaling (box 3) from field data to remotely sensed imagery to produce a MODIS-based fractional cover product.

This involves:

- determining the technical details of the optimal upscaling algorithm
- advising on the sampling framework for location of field sites
- advising on the timing of field data collection to be sufficiently co-incident with sensor/s overpass.
Upscaling

Upscaling is a way of taking information based in observations that have a small spatial (or temporal) domain and extending that domain to a larger geographic area (or time period). Crossing a resolution (or scale) boundary is a key feature of upscaling and is what distinguishes upscaling from aggregation (which is the process of combining data from smaller sub-regions). The dates of field work and image acquisition cannot be too far apart or else the characteristic being measured and estimated remotely may have changed (T McVicar [CSIRO] 2009, pers. comm., December).

Examples of upscaling techniques of vegetation characteristics relevant to this project include McVicar et al. (1996a,b), Milne et al. (2007) and Guerschman et al. (2009). These techniques are outlined in Appendix D.

Working group 3: Field data collection

The purpose of working group 3 is to validate remotely sensed fractional cover products for the purpose of monitoring ground cover levels.

This involves:

- agreeing on field methods for measuring ground cover (national standard)
- prioritising where to locate sites to measure ground cover
- agreeing on the timing and frequency of measurement at a site
- coordinating parties collecting field data, managing data and providing feedback.

Working group 4: Monitoring land management practices with remote sensing

The purpose of working group 4 is to develop a monitoring framework for ground cover management practices using remotely sensed fractional cover. In the mixed farming or cropping zone, this includes:

- advising on the sampling framework for location of field sites so key management practices (and land uses) are considered
- advising on the frequency and timing of field data collection of ground cover levels to capture the sequence of management practices for a site
- developing the metrics to interpret fractional cover time series for selected management practices (for example, timing and length of cultivated fallow, removal or retention of crop residues, timing and number of tillage passes, grazing pressure and practice, perennial pasture content, and conversion of continuously low productivity areas to perennial vegetation).

This working group will build on and seek to implement the recommendations of Stewart and Rickards (2010), focusing on selected sites in the cropping/mixed farming zone to complement the data collected through the Australian Bureau of Statistics’ Agricultural Resource Management Survey.
Workshop recommendations

The key recommendations from the workshop are listed below, under the four working groups.

Working group 1: Fractional cover mapping operational for the nation

- Use the method of Guerschman et al. (2009) to produce a fractional cover product for Australia as 500-metre 16-day composites of bare soil, photosynthetic and non-photosynthetic vegetative cover derived from MODIS imagery.
- Automate the delivery of this fractional cover product to allow updating every four days.
- Provide caveats on the use and limitations of the dataset.
- Seek to improve the dataset with further validation using:
  - flag analysis to identify areas where validation data are required (for example, map 4)
  - existing suitable site data available from state agencies (in particular the Queensland Department of Environment and Resource Management (DERM) and NSW Department of Environment, Climate Change and Water (DECCW))
  - new site data collected by state agencies, Geoscience Australia (GA), CSIRO and others (for example, the Grains Research and Development Corporation (GRDC)).
- Upscale from site data to Landsat and then to MODIS imagery. This is a more cost-effective and feasible way to collect field data and allows development of two ground cover products in tandem.
- Determine product accuracy (aiming for ±10–20 per cent error). Need to consider:
  - improving discrimination of low ground cover levels—those less than 50 per cent
  - estimating area at risk—whether overestimation or underestimation is better when targeting regions.

Working group 2: Upscaling

A successful upscaling strategy should be ensured through implementing the following protocols.

- Ensure field sites are accurately located using differential GPS technology.
- Ensure field data are collected using Queensland’s Statewide Landcover And Trees Study (SLATS) modified discrete point sampling method along 100-metre transects:
  - for pastoral environments using the star-shaped transect approach of Scarth et al. (2006)
  - for intensive agricultural environments with linearly sowed crops using the cross-transect method of Schmidt et al. (2010b) (figure 4).
- Ensure field crews are trained by DERM in the use of the SLATS modified discrete point sampling method—this is the agreed minimum national specifications for field data.
• Ensure field data are stored in a spatially enabled relational database that is compatible with the current Queensland PostGIS database (http://postgis.refractions.net/) to quickly generate a national database.

• Locate field sites in both homogenous herbaceous land covers and in more heterogeneous tree-shrub-grass mixed systems. Within a field site the land cover needs to be fairly homogenous and representative of wider conditions.

• Design the field work strategy to cover a wide range of soil colours (for example, white kaolinite clays, black cracking clays, red desert sands and yellow earths). Focus on collecting data for the various natural and agricultural systems in jurisdictions other than Queensland (because of their extensive SLATS field sites), with the exception of the black clays of central-western Queensland.

• Assess the impact of soil colour to improve the MODIS fractional cover product based on Guerschman et al. (2009) by having coincident at selected sites:
  – field collection using the SLATS modified discrete point sampling method
  – field level spectral radiometric observations—using a portable spectroradiometer (available from Analytical Spectral Devices Inc.)
  – Hyperion imagery—with the exact location specified before tasking this pointable hyperspectral sensor.

Note: Class 0: pixel processed normally, unmixing unconstrained; Class 1: unmixing partially constrained, fractional cover estimated; Class 2: unmixing constrained and fractional cover not estimated; Class 255: MODIS NBAR data not available. Source: Randall, workshop presentation.
Working group 3: Field data collection

In addition to the recommendations of the upscaling working group:

• Adopt the definitions of the Committee on Earth Observation Satellites (CEOS) Working Group on Calibration and Validation for validation and their validation hierarchy (box 4).

• Establish the relationship between monitoring ground cover obliquely and from overhead. This may allow use of existing obliquely viewed field measurements of ground cover (that is, windscreen surveys). Forward (2009) indicates there are more than 8130 sites from windscreen surveys in cropping and rangelands environments representing most jurisdictions that potentially could be used, also providing historical data (for example, South Australian data back to 1999–2000, and Victorian Mallee and Western Australian data back to 2007).

• Undertake a review of ‘human variability’ and its effect on the measurement of ground cover in the field for both rangelands and cropping. There is significant literature addressing this issue, particularly for the rangelands. This should underpin the adoption of the selected field method/s and its accuracy.

• Make minor modification to the SLATS generic site data form (Appendix E) to align with national standards for soil and land surveys (NCST 2009).

• Develop a statistically robust sampling framework that is representative of land uses and soil colours/types. The MCAS-S software tool (BRS 2009) could be used to prioritise where to collect ground cover measurements within this sampling framework.
• Adopt a stratified approach for the sampling framework. Determine whether one approach is suitable nationally or different approaches can be accommodated considering existing approaches. Examples include:
  – soil condition monitoring that is based on monitoring regions (broad landscape divisions based on physiographic regions), monitoring units (a combination of major soil types and land uses) and monitoring sites (locations within units where repeat sampling occurs using a 25-metre grid approach)
  – the Victorian primary production landscapes
  – stratification for the rangelands (under TERN).

• Establish a central registry of monitoring sites from all disciplines. This would require a champion organisation to bring together the disciplines and activities. The initial focus of this registry would be the sites identified in existing state monitoring programs that are relevant to ground cover and in particular aligned with the SLATS methodology (such an assessment has been undertaken by NCLUMI through the Australian Collaborative Land Use and Management Program (ACLUMP)—map 5).

box 4  Calibration and validation of remotely sensed data

Calibration is the process of quantitatively defining the system responses to known, controlled signal outputs (that is, sensor radiometric and geometric performance, and stability).

Vicarious calibration refers to techniques that make use of natural or artificial sites on the earth’s surface for the post-launch calibration of sensors.

Training refers to the process of developing and refining an algorithm designed to produce a specific data product from the system outputs.

Validation is the process of assessing, by independent means, the quality of the data products derived from the system outputs (that is, comparison and scaling of remotely sensed derived biophysical products versus in situ measurements). Validation is undertaken in four stages:

* Stage 1 validation: Product accuracy is assessed from a small (typically less than 30) set of locations and time periods by comparison with in situ or other suitable reference data.

* Stage 2 validation: Product accuracy is estimated over a significant set of locations and time periods by comparison with reference in situ or other suitable reference data. Spatial and temporal consistency of the product and consistency with similar products has been evaluated over globally representative locations and time periods. Results are published in the peer-reviewed literature.

* Stage 3 validation: Uncertainties in the product and its associated structure are well quantified from comparison with reference in situ or other suitable reference data. Uncertainties are characterised in a statistically robust way over multiple locations and time periods representing global conditions. Spatial and temporal consistency of the product and consistency with similar products has been evaluated over globally representative locations and periods. Results are published in the peer-reviewed literature.

* Stage 4 validation: Validation results for stage 3 are systematically updated when new product versions are released and as the time series expands.

Ensure that the field campaign implemented considers the seasons and overpasses of the satellite. Field measurements should at a minimum be twice per year, at the end of the wet and dry seasons, to correspond with maximum and minimum levels of cover.

Working group 4: Monitoring land management practices with remote sensing

- Modify the Queensland SLATS generic site data form (Appendix E) to include land management practices.
- Seek to standardise practice terminology for consistency with other monitoring programs (for example, windscreen/roadside surveys for erosion risk). Ideally this should align with the activities under the National Committee for Land Use and Management Information (NCLUMI)—namely the Australian Land Use and Management (ALUM) Classification and categories of the Land Use and Management Information System (LUMIS).
- Gather information required on the timing of land management practices throughout the year to assist in the interpretation of remotely sensed fractional cover time series. This could be achieved by:
  - providing a confidence estimate for the area represented by generalised ‘calendars of operations’ collected for natural resource management regions by the NCLUMI through ACLUMP
  - coordinating with other monitoring programs which collect information on land management practices multiple times per year (for example, windscreen surveys (SA, NSW, WA), Victorian Mallee survey) at known locations to be coincident with sensor overpass
  - compiling ‘paddock diaries’ of field operations (including stocking rates and weather events) at sites with the assistance of land managers using standardised terminology
  - visiting field sites at key changes in ground cover levels because of management practices to measure ground cover.
- Align management practices collected with those of the ABS Agricultural Resource Management Survey, with a focus on ground cover related practices.
Existing monitoring sites indicating those that have measured ground cover using the SLATS method

**Site suitability characteristics**
- ● ground cover measured using SLATS method
- ○ ground cover measured using other quantitative method
- ● ground cover not measured but possible

Source: Australian Collaborative Land Use and Management Program from data supplied by state and territory agencies.
Tables 1 and 2 outline the steps and estimates of the effort required to implement the recommendations of the working groups for a nationally coordinated approach to ground cover mapping using remote sensing. With a limited budget, the Department of Agriculture, Fisheries and Forestry (DAFF) has identified the extensive grazing systems of the rangelands (Bastin et al. 2008) as the focus for initial monitoring (map 6). The rangelands contain most of the areas where wind erosion is widespread (see http://www.nrm.gov.au/business-plan/10-11/priorities/sustainable/pubs/map-2-4-2.pdf) and where data is required to improve estimates of hillslope erosion by water (see http://www.nrm.gov.au/business-plan/10-11/priorities/sustainable/pubs/map-2-4-4.pdf). Priority will be given to those tasks that will most improve the MODIS-based fractional cover product for monitoring within the rangelands. The mixed farming or intensive land use zone will be considered for limited sites only to assist in national validation of the fractional cover product. The Caring for our Country website (http://www.nrm.gov.au) will provide progress on the implementation of these recommendations, within the available resources.

Agricultural non-woody areas of the rangelands are where the MODIS-based fractional cover of Guerschman et al. (2009) is required first for monitoring.
<table>
<thead>
<tr>
<th>Key tasks to deliver an operational remotely sensed fractional cover nationally (2010–2013)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>task</strong></td>
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</table>
| 1. Automate delivery of CSIRO's MODIS-based fractional cover product (version 0) | GA, CSIRO (CLW) | 4–5 months after project initiation | GA 0.5 FTE | Experimental product
| using GA’s NBAR data and the algorithm of Guerschman et al. (2009) | CSIRO 0.5 FTE | Limited validation |
| • product is updated every four days on 16-day 500-metre composites | • product distinguishes bare soil, non-photosynthetic and photosynthetic vegetation | Users experiences and caveats to be provided |
| • includes flag data (indication of reliability of cover estimate) | • includes metadata and documentation | Assessment of GA’s and CSIRO’s quality control of NBAR product and processing |
| 2. Undertake assessment of CSIRO’s MODIS-based fractional cover product considering: | GA, CSIRO (CLW) | Ongoing | GA 0.25 FTE (TERN funded) | Continuous improvement of MODIS fractional cover product
| • robustness of the algorithm – is it appropriate to apply nationally or are modifications required for different landscapes? | DERM and other state agencies to provide field data | State agencies to provide existing field data |
| • spectral characteristics – soundness of contrast of bands 6 and 7 (affected by soil moisture and soil colour) | • other unmixing models e.g. DERM’s ground cover index (GCI) | DERM to provide their GCI algorithm for MODIS imagery |
| • existing datasets available to test algorithm e.g. GCI and SLATS data |  | Coordination role for ACRIS with rangeland jurisdictions |
| 3. Release an improved version of CSIRO’s MODIS-based fractional cover product (version 1) | CSIRO (CLW), GA | To be advised (depends on field data collection campaign in table 2) | GA 0.25 FTE | Minimise uncertainty in the 40–60 per cent ground cover levels
| using a revised IDL algorithm based on the results from: – calibration sites | | CSIRO? | Use existing and new field data collected by the state agencies, CSIRO and GA |
| – high/medium-resolution data with upscaling | | | |
| – validation sites | | | |
| • with documentation to indicate differences between versions | | | |

continued...
### 4. Produce a Landsat-based (30 m) fractional cover product

- **lead organisation and partners**: DERM, DECCW, GA, CSIRO (CLW)
- **timeframe**: To be advised
- **estimate of effort required**: To be advised
- **comments**: TERN looking to standardise processing of Landsat imagery to avoid duplication of effort (February 2010 workshop). Extensive field data available for Queensland under pastoral land uses. Requires lots of validation data (600 sites available for Queensland with plans for 200–300 sites for NSW). Useful for targeted regions rather than wall-to-wall mapping.

*Task 1 could be deferred to later in the project after development of version 1 of the MODIS-based fractional cover.*
### Key tasks in the validation of remotely sensed fractional cover (2010–2013)

<table>
<thead>
<tr>
<th>task</th>
<th>lead organisation and partners</th>
<th>timeframe</th>
<th>estimate of effort required</th>
<th>comments</th>
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</table>
| 1. Personnel training in field data collection  
* underpinned by a field manual which includes a site form  
* measurement of vegetation fractions which uses the:  
  – star-transect method for pastoral environments  
  – cross-transect method for linearly sown crops  
* measurement of soil spectral reflectance | DERM/DECCW and all state agency partners | Manual – draft for commencement of training; final draft at completion of training  
Training to occur over 6–12 months after project initiation | To be advised | Current SLATS generic site data form to be improved/modified (e.g. to include existing national standards for soil and land surveys (NCST 2009) for surface condition and land management practices (need for standard terminology))  
Personnel training to occur in different environments throughout Australia (at least one rangeland site and one cropping site per state). This training exercise can be used to compare the SLATS methodology with existing state-based programs  
Field data to be collected for a 100 metre x 100 metre site (suitable for Landsat and upscaling to MODIS) |
| 2. Sampling framework  
* statistically robust  
* considers seasonality, land uses, soil colour  
* aims to time sampling to coincide with satellite overpass  
* seeks a staged approach to validation of the fractional cover product  
* uses MCAS-S to prioritise site locations based on factors such as erosion risk, flag analysis etc | ABARES and CSIRO (CMIS) | 2–3 months following an experts workshop after project initiation | To be advised | Consider level of accuracy required and the image sensor product being validated (e.g. MODIS versus Landsat)  
Consider existing stratifications used for monitoring nationally and within states (e.g. soil condition monitoring, Victoria’s primary production landscapes) |

*continued...*
2 Key tasks in the validation of remotely sensed fractional cover (2010–2013)  continued

<table>
<thead>
<tr>
<th>task</th>
<th>lead organisation and partners</th>
<th>timeframe</th>
<th>estimate of effort required</th>
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<tr>
<td>3. Spatially enabled relational database for field data</td>
<td>ABARES</td>
<td>Ongoing commencing</td>
<td>To be advised</td>
<td>Explore options for electronic entry of data within the field</td>
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<td>* compatible with current database which uses POSTGIS</td>
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<td>once data is received from training (Task 1)</td>
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</table>
| 4. Field data collection campaign                                   | All state agency partners      | To commence following training and to continue to May 2013 | 0.01 FTE per day in the field (this equates to approximately $1000 per site per visit including travel expenses) | 2–3 people required for each site visit  
Time at each site using DERM’s SLATS method:  
* ~90 minutes for woodlands  
* ~40 minutes for rangelands (no trees)  
* ~30 minutes for cropping  
Align campaign with interested others (e.g. GA, CSIRO, GRDC, CMAs). |
| * underpinned by sampling framework                                |                                |                                 |                             |                                                                                                                                          |
| * staged approach                                                   |                                |                                 |                             |                                                                                                                                          |
| * data collected twice yearly as a minimum (wet and dry season)    |                                |                                 |                             |                                                                                                                                          |
| 5. Establishment of supersites                                     | ABARES/CSIRO (CLW) with state agency partners | Select sites to cover range of environments, particularly those where the fractional cover product needs most improvement |                             |                                                                                                                                          |
| * selected targeted sites where detailed field measurements are made of ground cover, spectral reflectance, land management practices |                                |                                 |                             |                                                                                                                                          |
| * trial Upscaling techniques                                       |                                |                                 |                             |                                                                                                                                          |
| * trial metrics for detection of selected land management practices in mixed farming/cropping |                                |                                 |                             |                                                                                                                                          |
### Workshop presentations

<table>
<thead>
<tr>
<th>Presentation Title</th>
<th>Presenter</th>
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</table>
| Ground cover monitoring for soil condition reporting | Mr Ian Thompson  
Executive Manager, Sustainable Resources Management, Department of Agriculture, Fisheries and Forestry |
| Ground cover inputs for wind and water monitoring and modelling | Dr Michele Barson¹ and Dr John Leys²  
¹Science Advisor, Australian Government Land & Coasts, Department of Agriculture, Fisheries and Forestry  
²Principal Research Scientist, Scientific Services Division, NSW Department of Environment, Climate Change and Water |
| Fractional cover for Australia: scaling from the field to MODIS | Dr Juan Guerschman  
Research Scientist, Environmental Earth Observation Research Group, CSIRO Land and Water |
| Towards image-based monitoring of soil erosion risk in South Australian agricultural land | Dr Ken Clarke  
School of Earth and Environmental Sciences, University of Adelaide |
| A national dynamic land cover capability | Dr Leo Lymburner  
Remote Sensing Applications Specialist, National Earth Observation Group, Geospatial and Earth Monitoring Division, Geoscience Australia |
| Ground cover in cropping environments using Landsat and MODIS | Dr Michael Schmidt  
Scientist, Remote Sensing Centre, Queensland Department of Environment and Resource Management |
| Mapping and monitoring of the soil surface using remote hyperspectral imaging | Dr Thomas Cudahy  
Group Leader, Minerals and Environmental Sensing, CSIRO Exploration & Mining |
| Bushfire CRC project: improved methods for assessment of grassland curing | Dr Ian Grant  
Space Based Observation Section, Bureau of Meteorology |
| Calibration and validation – analysis of CSIRO fractional cover product | Dr Lucy Randall  
Senior Scientist, Land and Forest Sciences, Australian Bureau of Agricultural and Resource Economics and Sciences |
| A very brief update on ground cover mapping in NSW | Mr Tim Danaher  
Remote Sensing Section, Department of Environment, Climate Change and Water |
| Wireless sensor networks for monitoring ground cover change – a case study | Dr Andre Zerger  
CSIRO Sustainable Ecosystems |
| Wrap-up and options | Dr John Leys  
Principal Research Scientist, Scientific Services Division, NSW Department of Environment, Climate Change and Water |
| Calibration and validation for remotely sensed ground cover: what is required? | Dr Tim Malthus  
Research Group Leader, Environmental Earth Observation, CSIRO Land and Water |

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Note: These presentations are available to workshop participants and interested others via the ground cover monitoring GovDex site. Alternatively, contact the authors for access to the above presentations.
## Workshop participants

<table>
<thead>
<tr>
<th>name</th>
<th>state</th>
<th>organisation</th>
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</tr>
</tbody>
</table>

a Workshop presenter. b Workshop chair. c Attended first day of workshop only. d Attended second day of workshop only. e Working group member.

1 Implementing MODIS-based fractional cover mapping operationally for the nation. 2 Field data collection. 3 Upscaling. 4 Monitoring land management practices with remote sensing.
Introduction

The sustainable practices target for Caring for our Country focuses on improving the condition of the soil resource through the adoption of better land management practices. Four indicators of resource condition, identified through the work of the National Land and Water Resources Audit (and endorsed by the Audit Advisory Council)—wind erosion, water erosion, soil acidification and soil carbon—will be used to help report on the condition of Australia’s soil resources and the longer term effect of land management practices on condition.

Caring for our Country, working in collaboration with state agencies, CSIRO and other research organisations, has invested in a series of projects aimed at improving Australia’s capacity to monitor wind erosion (Forward 2009; Leys et al. 2009, 2010; McTainsh et al. 2010; Mitchell et al. 2010), water erosion (Leys et al. 2009; Bui et al. 2010), soil acidification and soil carbon (Baldock et al. 2009; Ringrose-Voase in preparation). These projects have recommended bringing together data from a number of sources to monitor soil condition indicators by combining ground-based sampling, remote sensing and spatially explicit modelling. A number of the data inputs required for this monitoring will need to be developed or improved—proposals for this work are currently being considered.

High frequency (monthly) spatially explicit ground cover (vegetation, biological crusts and stone that is in contact with the soil surface) data are needed to improve wind and water erosion modelling and monitoring. Most methods used to estimate cover values have not been able to account for dead and dry vegetation, which has frequently been classified as bare ground, leading to overestimates of the rates of erosion (Hairsine et al. 2009).

Spatially explicit ground cover data has also been identified as an input needed to improve soil carbon and pH modelling proposed under the national soil condition modelling project. Additionally, monthly ground cover data will contribute to understanding the impact of climate variability on pasture condition, particularly in the rangelands.

Wind erosion modelling for resource condition reporting

The CEMSYS (Computational Environmental Management System; Shao et al. 2007) model is recommended (Leys et al. 2009) for evaluating the frequency and intensity of wind erosion across Australia, and has been used by Caring for our Country to identify where improving soil and land management practices to reduce soil loss from wind erosion will provide the biggest benefits (Smith and Leys 2009). CEMSYS estimates the onsite soil loss and the offsite dust concentration at national, state and (some) regional scales and provides monthly maps of wind erosion rates at 50-kilometre resolution for the Australian continent and 10-kilometre resolution for New South Wales. The spatial resolution for wind erosion modelling is limited by the resolution of the GIS data (soil texture, soil type, vegetation, roughness) and that of...
Ground cover monitoring for Australia  

**Spatial and temporal scales**

For ground cover (woody and non-woody), the following specifications are required of data layers for use in modelling wind erosion (using CEMSYS) at the national scale (with applicability at the state and regional scale):

- spatial resolution: 500 to 1000-metre resolution
- temporal resolution: monthly
- domain would be: Australia-wide (lower left corner 112 east to 45 south, upper right corner 155 east to 10 south)
- preferred file format would be ARC-ACSII format.

**Non-woody cover**

Ideally fractional non-woody cover estimates would be classed as follows:

- physical soil crusts
- disturbed/loose soil
- cryptogamic soil crusts
- live (that is, photosynthesising)
- dead vegetation cover (that is, non-photosynthesising vegetation)
- litter
- rock.

Interim non-woody fractional cover estimates could be classed as follows:

- photosynthetic vegetation (PV)
- non-photosynthetic vegetation (NPV)
- bare ground (BG).

**Woody cover**

Fractional woody cover (proportion of photosynthetic vegetation contributing to the overstorey) is also required for:

- spatial resolution: 500 to 1000-metre resolution
- temporal resolution: annual
- domain would be: Australia-wide (lower left corner 112 east to 45 south, upper right corner 155 east to 10 south)
- preferred file format would be ARC-ACSII format.
Water erosion modelling for resource condition monitoring

Currently SedNet (Sediment and nutrient budget model (Wilkinson et al. 2004)), which includes the Revised Universal Soil Loss Equation (RUSLE), is recommended for modelling water erosion nationally down to the regional scale (Leys et al. 2009). WaterCAST, being developed at the eWater Cooperative Research Centre, is viewed as having the potential to replace SedNet in the future for assessment at catchment level and possibly state and national level (Leys et al. 2009) but at present data are inadequate for model parameterisation.

SedNet models sediment loads from hillslope, gully and streambank erosion and models nutrient loads providing long-term annual average estimates at 5-kilometre resolution. Improved differentiation of bare ground and dead or bleached vegetation in the satellite image interpretation used as measures of cover in the RUSLE calculations would improve model outputs (Hairsine et al. 2009). Higher resolution inputs such as for land use and vegetation, the introduction of a land management term in addition to a cover term and improved soils data have also been identified as priority improvements needed in the assessment of soil erosion by water (following NLWRA program of 2001–2003) (see Leys et al. 2009, p. 43). Some of these issues have been addressed for case studies but have yet to be applied nationwide.

Spatial and temporal scales
For ground cover, the following specifications are required of data layers for use in modelling water erosion (using SedNet) at the national to regional scale:

- spatial resolution: 500 to 1000-metre resolution
- temporal resolution: monthly
- domain would be: Australia-wide (lower left corner 112 east to 45 south, upper right corner 155 east to 10 south)
- preferred file format would be ARC-ASCII format.

Non-woody cover
Fractional non-woody cover estimates are required for:

- photosynthetic vegetation (PV)
- non-photosynthetic vegetation (NPV)
- bare ground (BG)
- rock.

Interpretation of fractional cover into management practice classes (such as crop versus fallow) would improve cover estimate in RUSLE.

Monitoring agricultural land management practices
Caring for our Country sustainable practices funding is focused on improving the uptake of practices which will reduce soil loss through wind and water erosion, manage the soil
acidification risk and increase soil carbon storage. Practices of particular interest include those which increase the proportion of ground cover present year round.

The biennial ABS Agricultural Resource Management Survey provides information reported by farmers on the uptake of land management practices at NRM region level for Caring for our Country reporting. There may be opportunities for providing an additional line of evidence on the impact of certain management practices on ground cover at a small number of sites within the intensively used agricultural zone.

**Spatial and temporal scales**
For national, state and regional assessment of ground cover levels to support Caring for our Country reporting, the following are required:

- spatial resolution: generally 30-metre but up to 500-metre resolution (influenced by paddock size—resolution less if want to assess within paddock variation)
- temporal resolution: annually (at minimum cover or at time of most risk) to monthly—time-series required
- coverage: rangelands and intensive land use zones of Australia.

**Non-woody cover**
Fractional non-woody cover estimates are required for:

- photosynthetic vegetation (PV)
- non-photosynthetic vegetation (NPV)
- bare ground (BG).

Within the intensively used agricultural zone, methods to measure fractional cover and to interpret remotely sensed fractional cover estimates into key management practices related to ground cover maintenance should be trialled at selected sites. Such management practices include:

- cultivated fallow (bare soil, timing and length)
- crop residue (left or removed; timing and length)
- grazing pressure (ground cover (PV+NPV) > 50 per cent).

Stewart and Rickards (2010) indicate potential options for monitoring land management practices using remote sensing in the intensively managed agricultural zone.

**Calibration and validation of remotely sensed ground cover products**
A remotely sensed ground cover product is underpinned by on-ground measurement of the features being estimated. To implement production nationally, agreement must be reached
on the location of ground control sites and what is measured at each site. A separate issue is agreement on the processing steps to produce the remotely sensed ground cover product.

To establish a national network of control sites for remote sensing of ground cover, the following steps are suggested:

1. Develop and evaluate a core set of attributes for describing and mapping ground control sites.
2. Review and test methods needed for field-based collection of new ground control sites to ensure suitability of use in all jurisdictions for all agricultural systems (including the rangelands).
3. Review existing sites against the agreed core set of attributes.
4. Undertake a statistical analysis to identify the numbers and likely locations of sites needed to adequately represent spatial variability of all agricultural systems.
5. Compare existing sites with sites needed according to the statistical analysis to identify gaps in the national ground reference sites database.
6. Develop an investment plan (taking into account available budget) to collect the data needed for additional ground control sites.
7. Agree arrangements, methods, costings and timelines with agencies participating in the on-ground collection.
8. Collate ground control site data.
9. Make ground control site dataset publicly available via the web.

Methods for on-ground measurement of ground cover fractions should be assessed on the usefulness of the information to inform reporting, capacity to migrate methods across environments, and suitability for multiple sensors (for example, MODIS and Landsat). These control sites will need to meet the needs of image-based ground cover mapping at national, state and regional scales. Establishment of new control sites to improve the reliability of the remotely sensed outputs must be prioritised.
Example 1: Leaf area index

Figure 5 shows how an upscaling methodology can be used to extend the spatial domain of measurements initially made over a much smaller area than the final relationships are used for. In this example, 1 m² field observations of leaf area index (LAI) in homogeneous herbaceous (that is, cropping and grazing) fields were destructively sampled, and step one (McVicar et al. 1996a) involved relating this site data to Landsat TM data, enabling production of a Landsat TM based LAI image. Step two (McVicar et al. 1996b) involved developing relationships between the Advanced Very High Resolution Radiometer (AVHRR) data and the Landsat TM based LAI image. The AVHRR LAI estimate was then estimated for the entire Murray–Darling Basin.

Example 2: Ground cover and biomass

Milne et al. (2007) evaluated MODIS for estimating ground cover and biomass/feed availability in mixed tree-grass grazing systems (for example, tropical savannah). Foliage projective cover and biomass was collected at 100 by 100-metre field sites. Field measurements were related to the 1-kilometre MODIS cells in which they reside by weighting an observation based on a ratio between the scaled up Landsat TM (30-metre cells) bare ground data at 100 by 100-metre
(the field site area) and the scaled up Landsat TM bare ground at the MODIS 1-kilometre pixel resolution. The project centred on Charters Towers and the Brisbane Valley but the methodology (or upscaling technique) could be equally applied across all of Queensland.

Example 3: Fractional cover

Guerschman et al. (2009) linked field-level spectral radiometric observations (made with a portable spectroradiometer from Analytical Spectral Devices, Inc) to Hyperion (30-metre resolution) hyperspectral satellite data. End-members relating to the pure components of photosynthetic vegetation, non-photosynthetic (senescent) vegetation and bare soil could be distinguished in both sets of hyperspectral data. To upscale to the MODIS resolution (a broadband instrument, like Landsat, which does not have all the hyperspectral bands of the spectroradiometer and Hyperion), they developed spectral surrogates using an optimally selected set of MODIS bands to capture the information content in the hyperspectral imagery. This enabled the unmixing of two MODIS indices to map the fraction of photosynthetic vegetation, senescent vegetation and bare soil at the MODIS resolution.
Site Description

Site Number: ___________ Date: ___________

Zone: ___ Datum: _____ Easting: ___________ Northing: ___________

Bearing (to GPS): _______ Distance (to GPS): _______

Film No: _____ Photo Nos: ________________________________

Description: ____________________________________________________________________________

_______________________________________________________________________________________

_______________________________________________________________________________________

Landform (Crest; Upper; Mid; Lower; Flat; Closed; Open): ___________

Slope %: _____ Aspect: _____

Soil Colour:

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<th>Crust Dry</th>
<th>Dist. Dry</th>
<th>Adtnl. Dry</th>
<th>Crust Wet</th>
<th>Dist. Wet</th>
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Cryptogam %: _____ Cryptogam colour: ___________

Rock/Lag Colour:

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<tr>
<th>1st Dominant</th>
<th>2nd Dominant</th>
<th>3rd Dominant</th>
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Rock/Lag % est.: _____ Biomass est. (kg/ha): ___________

Grass height (cm): _____ Fire: ___________

Faunal activity: _____ Faunal type (Cattle; Sheep; Macropod; Termites; Ants; Locust): _____

Crust Brokenness (Extensively broken; Moderately broken; Slightly broken; Intact): ___________

Erosion Features (Rills; Terracettes; Sheeteting; Scalding; Hummocking; Pedestalling): ___________

Deposited Material (Extensive; Moderate; Slight; Insiginificant): ___________

Soil Microtopography (Smooth; Shallow depressions; Deeper depressions; Deep formations; Very deep and extensive): ___________

Surface Nature (Non-brittle; Very hard; Moderately hard; Easily broken; Loose-sandy): ___________
Vegetation description:

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<tr>
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<th>1&lt;sup&gt;st&lt;/sup&gt; Dom by biomass</th>
<th>%</th>
<th>2&lt;sup&gt;nd&lt;/sup&gt; Dom by biomass</th>
<th>%</th>
<th>3&lt;sup&gt;rd&lt;/sup&gt; Dom by biomass</th>
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<td>Grasses/Forb</td>
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Overstory height: Observer:________ % Slope at 20m:_____

TBA:

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Total Live TBA (Sum Converted TBA / 7):______m²/ha

Weights: No. Q’s:_____ Total Wet Weight :_______g Sub Sample Wet Weight :_______g

Sub Sample Dry Weight :_______g TSDM :_______kg/ha
## Site Transect

Site Number: ___________  Sheet Number: _____  Date: ___________  Bearing: _______

Zone: _____  Datum: ________  Easting: ________  Northing: ________

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| Zone | Datum | Easting | Northing | CRUST | DIST | ROCK | GREEN | LF | DEAD | LF | LITTER | CRWN | OVER | OVER | CRWN | OVER | OVER | OVER | OVER |
|------|-------|---------|----------|-------|------|------|-------|----|------|----|--------|------|-------|-------|------|-------|-------|-------|-------|-------|-------|
| _____ | _____ | ______ | ______ | _____ | _____ | _____ | _____ | ____| _____ | ____| _____ | ____| _____ | _____ | _____ | _____ | _____ | _____ | _____ | _____ | _____ |
Site selection criteria

- Sample the full range of cover from 0 to 100%.
- Sample a range of soil colours and textures.
- Sample a range of TBA from 0 to approx 10m²/ha (although upper limit yet to be determined).
- Sample a range of understory cover amounts.
- Ideally locate paired sites across fence lines sampling a contrasting cover on either side.
- Locate in areas of uniform density and species mix for a minimum patch size of 300 x 300m if possible (larger if non DGPS).
- Locate a minimum of 100 metres from roads or other features not characteristic of the vegetation being measured (from the edge of site).
- Locate away from water run-on areas if possible.
- On level or near level ground.
- If a sloped site is necessary, avoid western and southern slopes (these are affected by shadow due to winter and morning sun angles).

Groundcover

- The following table should be used to help select a suitable prism for a basal area measurement. Try to choose a prism which will give a plot radius of 15-20m.
- If the plot radius is larger make sure that its in a uniform area.

Optical Wedge Calibration

- Place a vertical line on the target using a marker pen. Hold the wedge at the measured distance (d) from the target and look through it at the line. Get a second person to draw another line, marking the displacement seen through the wedge.

Transcet recording

- Minimum 300 sample points (100m transect tape x 3).
- Transect tapes laid strictly in a 0, 60 and 120 deg star pattern. The site centre is located at the intersection of the star.
- Measure in order of 0 – 180 deg. 60 – 240 deg and 120 – 300 deg for consistency.
- Averaged DGPS or GPS position at site centre (minimum 3-5min averaging for DGPS, longer for non DGPS). Recorded as UTM (Eastling and Northing) with associated Zone and using default Datum WGS84. (Use UTM, Datum GDA94, Spheroid GRS1980 if available on GPS).
- Care should be taken when placing the pole at each metre mark - read the ground cover first by looking vertically (or using a thin steel wire rod) above the tape thus avoiding crushing or moving a prospective grass/litter attribute. A laser pointer taped to the pole is more useful in areas with significant understory e.g. heath.
- Before recording make sure both the observer and recorder are clear as to the classes being measured. Call in order of ground layer, mid layer, overstorey e.g. crust; mid (storey) green (leaf); crown; over (storey) branch.
- If recording hard copy sheets, care must be taken when reducing the measurements - have someone check the adding up and also the logic.
- If using a GRS Densitometer, both spirit levels must be centred and the recording spot centred in target circle.
- If using a gimballed sighting tube, the tube MUST BE FREE to ROTATE on the gimbal, otherwise operator bias WILL BE INTRODUCED.

Site selection criteria

- If two people first go into the field they should both take BA wedge measurements at several sites to check if one or the other is systematically measuring more or less than the other [strict blind testing procedure advised].
- The possible reasons for bias are:
  - instead of counting every second “split” tree as “in”, the operator leaves all “out” or puts all “in”... (error = 0.5xthe number of “split” trees)
  - not keeping the wedge at the site centre – i.e. rotating the wedge around the body at arms length (error is most significant where site position is amongst bushes that may be counted as solid trunks if the wedge is close enough)
  - not looking behind large trees near the observer – can move off centre to check, keeping perpendicular... (error nil to quite large)
  - using the wrong thickness wedge relative to the tree/bush trunk thicknesses (error can vary depending upon site and or the operator)
  - poor eyesight - not being able to clearly see distant trees - thus leading to a preference for using a wedge that has a shorter measurement range (error generally in reading less trees than exist at the site)
  - not measuring/looking at the tree trunk at breast height – 1.3 m (error depends on tree thickness but if looking low the counts will be higher than they should be).

The following table should be used to help select a suitable prism for a basal area measurement. Try to choose a prism which will give a plot radius of 15-20m. If the plot radius is larger make sure that its in a uniform area.

Optical Wedge Calibration

1. Set up a target such as a white board or wall at least 5 metres from where the wedge is held. Use up to 10 metres if you can see well as a greater distance is better.
2. Place a vertical line on the target using a marker pen. Hold the wedge at the measured distance (d) from the target and look through it at the line. Get a second person to draw another line, marking the displacement seen through the wedge.
3. Measure this distance (w) in the same units as (d).
4. Calculate the basal area factor as follows:

   Basal Area Factor (BAF) = \( \frac{1000}{(1+4*(d/w)^2)} \)

   where \( d \) = distance to target; \( w \) = displacement width e.g. \( d = 5m, w = 0.1m; BAF = 1.0 \)

Plot radii (metres) as a function of prism factor and tree diameter

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References


