Field measurement of fractional ground cover

Australian Government

Australian Bureau of Agricultural and Resource Economics and Sciences

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A technical handbook supporting ground cover monitoring for Australia

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ACLUMP

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Australian Bureau of Agricultural and Resource Economics and Sciences
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Terrestrial Ecosystem Research Network

Acknowledgements

The handbook describes the fractional vegetation cover field observation method developed by numerous staff at the Queensland Department of Environment and Resource Management (DERM) Remote Sensing Centre. The Australian Government Department of Agriculture, Fisheries and Forestry (DAFF) funded the handbook development as part of the 'Ground cover monitoring for Australia' project. Training conducted by DERM in all states and the Northern Territory in this fractional vegetation cover field observation method has informed handbook development. Publication of the handbook under the Australian Collaborative Land Use and Management Program (ACLUMP) reflects the national adoption of the method described and implemented for ground cover monitoring.

ACLUMP is coordinated by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) and involves collaboration with a number of national, state and territory agencies. State partners coordinating ground cover monitoring in their jurisdiction are the Western Australian Department of Agriculture and Food; the New South Wales Office of Environment and Heritage; the Northern Territory Department of Natural Resources, Environment, the Arts and Sport; the South Australian Department of Environment and Natural Resources; the Queensland Department of Environment and Resource Management; the Tasmanian Department of Primary Industries, Parks, Water and Environment; and the Victorian Department of Primary Industries. National partners involved in ground cover monitoring include the Commonwealth Scientific and Industrial Research Organisation, Geoscience Australia, the Terrestrial Ecosystem Research Network and the Australian Government Department of Agriculture, Fisheries and Forestry. Substantial financial contributions have been made by each of the partners collaborating in this activity.

Foreword

Ground cover plays an important role in Australia's environmental, agricultural and economic sustainability. Protective ground cover is effective in reducing sediment loss through wind and water erosion. It also supports a diverse range of biodiversity and aids carbon sequestration and storage. More broadly, the agricultural industry depends on ground cover information for pasture and crop cover assessment and maintenance of ecosystem function and land condition.

Government programs which monitor ground cover levels using medium-resolution satellite imagery are established in some states. The data these programs produce are used for a variety of applications and decision making. For example, in Queensland, a structured program is monitoring the levels and changes in ground cover for the catchments adjacent to the Great Barrier Reef, while other monitoring programs are contributing to land condition assessments, State of the Environment reporting, and regional reporting. Ground cover information played an important role in assessing the impacts of the 2010–11 flooding and cyclone Yasi, which devastated much of Queensland in early 2011, and will continue to inform decision making as part of the recovery and reconstruction. Other broad-scale programs in Australia, such as AussieGRASS and Pastures from Space, are monitoring and predicting pasture and biomass levels to help graziers improve stock management and land management decision making. Some states monitor ground cover in cropped areas for assessment of erosion risk, in particular wind erosion. Importantly, all of these programs are supported by rigorous, quantitative field data which is used to calibrate and validate the products derived from satellite imagery.

It is with this background that the National Committee for Land Use and Management Information supports the need for nationally consistent methods for ground cover measurement. *Field measurement of fractional ground cover* is produced by the Australian Collaborative Land Use and Management Program (ACLUMP) as a technical handbook to provide quantitative methods for measuring ground cover at field sites to underpin spatial fractional vegetation cover datasets derived from satellite imagery. These datasets distinguish between the living and dry/dead vegetation and bare soil. The methods described in the handbook are also applicable to monitoring foliage projective cover or tree cover. Importantly, this handbook facilitates gathering of consistent fractional vegetation cover data for Australia, and will enable calibration, validation and ultimately improvement in accuracy to national remotely sensed products of fractional vegetation cover.

I hope the material presented in this handbook will be a significant and valued resource for measuring and monitoring ground cover for scientists, planners and practitioners in government agencies and organisations involved in designing, implementing and reporting strategies for sustainable land management.

P A Lawrence

Dr Paul Lawrence
Chair
National Committee for Land Use and Management Information

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Purpose and use of the handbook

This handbook has been compiled to aid systematic field observation and recording of vegetative and non-vegetative fractional cover. It will be used by all states and the Northern Territory to establish a national network of ground cover sites in landscapes managed for grazing and broadacre cropping. The data collected as described in this handbook will be used to calibrate and validate large area fractional cover spatial datasets derived from remote sensing. These spatial datasets are produced regularly—monthly, seasonally, annually—enabling change in ground cover to be monitored consistently across Australia. Monitoring ground cover indicates the vulnerability of the land to soil erosion, biodiversity and productivity loss. This provides a valuable tool to quantify and communicate the effects of management actions.

The handbook uses many site description attributes from the *Australian soil and land survey field handbook* (NCST 2009), which should be used in conjunction with this handbook. A notable difference is the attributes and descriptions used for vegetation structural classification. The handbook uses a simplified version of the vegetation structural classification described by Hnatiuk et al. (2009). The field data are observed as cover fractions within three strata:

1. non-woody vegetation including vegetative litter near the soil surface
2. woody vegetation less than 2 metres
3. woody vegetation greater than 2 metres.

The simplified structural description discriminates the cover fractions within the vertical vegetation profile for the purpose of calibrating and validating remotely sensed products. Survey programs may adopt a more detailed vegetation structural classification such as Hnatiuk et al. (2009). If fractional cover data are collected systematically and consistent terminology used, the data can be simplified post-survey to the broad vegetation strata used in the handbook.

The methods and attributes have been developed to be simple, systematic and repeatable to ensure consistency in the data collected. All field operators should undertake regular training and calibration exercises and record site observations as they are, not as they may have been.

1 Introduction

Ground cover is the non-woody vegetation (forbs, grasses and herbs), litter, cryptogamic crusts and rock in contact with the soil surface. Ground cover changes in response to climate variables, vegetation dynamics and land management. Factors such as grazing pressure, tillage and stubble practices, drought and fire all affect ground cover. The quantity of ground cover affects water infiltration, runoff, erosion and carbon sequestration. It is a key indicator of land condition such as soil degradation, pasture production and biodiversity. Estimates of ground cover and changes in the quantity and spatial arrangement of ground cover over time provide land managers, policy-makers and scientists with valuable information for use in planning, monitoring and modelling applications (Schmidt et al. 2010b).

Ground cover can be monitored using remote sensing. From a remote sensing perspective, ground cover is the fractional cover of the non-woody vegetation and litter near the soil surface. This definition is based on the spectral reflectance properties of the ground cover components. Thus superficial rock is excluded as current satellite systems cannot reliably distinguished it from the underlying soil—as is often the case for cryptogamic crusts. The field measurement protocol described in the handbook is used to derive three categories of cover from satellite imagery—photosynthetic vegetation (PV), non-photosynthetic vegetation (NPV) and bare soil (BS). In relation to these categories, ground cover is the sum of PV and NPV.

Remote sensing enables ground cover to be monitored consistently over large spatial extents, at multiple scales and through time. This is an evolving area of application in Australia (Danaher et al. 2010; Karfs et al. 2009; Ludwig et al. 2007) as remotely sensed methods are developed to estimate fractional ground cover (Guerschman et al. 2009; Scarth et al. 2010; Schmidt et al. 2010a), the time-series of imagery extends to decades and imagery is more freely available. All remote sensing methods require observation data to be collected to calibrate and test the approaches. Coordinating data collation to agreed protocols will hasten these developments and product accuracy (Leys et al. 2009).

At the national scale, monitoring ground cover using remote sensing is critical for assessment of environmental targets related to soil erosion and land management, as promoted by the Caring for our Country program. The MODIS-derived vegetation product of Guerschman et al. (2009) has been selected for this purpose (Stewart et al. 2011). It enables national, monthly monitoring of ground cover separating the PV and NPV components. For confidence in its ground cover estimates it requires more extensive calibration and validation. Adoption of a national standard for measuring fractional vegetation in the field will aid its improvement (Stewart & Rickards 2010; Stewart et al. 2011). This handbook provides the national standard having been trialled in all states and the Northern Territory by ACLUMP partners. These partners are now establishing a national network of sites for calibration, validation and improvement of remotely sensed fractional cover products which are measured at a scale suitable for Landsat and MODIS imagery. The initial focus is the extensive grazing systems of the rangelands with limited sites in the mixed farming or intensive land use zone (Malthus et al. in preparation). Effort will be focused on obtaining a wide spatial coverage of sites, with limited site revisits for temporal coverage.

The handbook draws on ABARES (2011), Forward (2009), NCST (2009) and Tongway & Hindley (1995), for site description; and Brady et al. (1995), Scarth et al. (2006) and Schmidt et al. (2010b) for the modified discrete point transect sampling methods. Although the focus of the handbook is ground cover, the methods described are appropriate to represent total vegetation cover, and its components, including foliage projective cover.

Figure 1 outlines the procedure to use to create national fractional ground cover mapping using remote sensing. Site selection and characterisation and collation of the data into a national database underpin the models developed and products produced using satellite imagery. The sampling effort should be reviewed annually and modified to meet information needs of derived fractional cover products and inclusion of additional sites as further resources become available (Malthus et al. in preparation).

1 Procedure to use to create remotely sensed fractional cover products to monitor ground cover

Data analysis informs future site selection

site selection

- Identify likely sites considering site selection criteria and national sampling strategy
- Site sampling stratification includes soil colour or type; full range of fractional cover; areas dominated by non-woody vegetation under grazing or cropping; flat homogeneous areas of at least 500 x 500 metres; clustering of sites (5) within a Landsat scene

Time data collection to satellite overpass with imagery cloud free.
The exact location of a site is determined by landholder consent and on-ground inspection.

site characterisation

- Select appropriate transect sampling method based on land use—star-shaped (300 observations) for pasture environments; cross-shaped (200 observations) for crops in parallel rows—layout transects
- Describe site, recording its location using a GPS and vegetation, land surface and soil features; take site photos
- Measure vegetation height, tree basal area, soil and rock/lag colour, size of rock/lag
- Record observations every metre along each transect of fractional cover for the ground layer, woody vegetation less than 2 metres and woody vegetation greater than 2 metres

data collation

- Scan and retain paper forms (if used)
- Enter site description and transect measurements into electronic forms
- Save forms and site photos with site_id prefix
- Data compiled into a national database

data analysis

Using MODIS and/or Landsat imagery:
- Spectral unmixing of satellite imagery to determine fractional cover components
- Calibration and validation of model/s using site data
- Accuracy assessment of derived fractional cover product/s

ground cover monitoring

2 Survey design

The site

A site is defined as a small area of land representative of the landform, vegetation, land surface and other land features associated with the observation (NCST 2009).

Sites should be chosen based on their representativeness and homogeneity. A homogeneous site has cover and species composition spatially distributed consistently over the site. The site should also have minimal topographic variation. The aim is for the reflective characteristics of the site to be consistent in the imagery for which the field data will be used to calibrate or validate.

The survey design should ensure that site locations sample and represent different landforms and soil characteristics, the range of vegetation types, and the spatial arrangement and structure of the vegetation of the study area. Surveys conducted to ground-truth fractional cover estimates from satellite imagery should choose sites that consider the spatial, spectral and temporal resolution of the imagery to be classified and the scale of the output products. Product accuracy depends on adequate, representative and objective site selection.

Scale

For the purpose of national fractional ground cover mapping, the primary aim is to relate field measurements to medium resolution imagery from the Landsat satellite missions (30-metre pixel resolution). To produce reliable estimates from the Landsat imagery, a site should be at least one hectare (100 × 100 metres), covering a 3 × 3 pixel area. Where possible, the area surrounding the site should be homogenous of at least 25 hectares (500 × 500 metres) for upscaling to MODIS imagery (with a 500-metre pixel resolution).

Figure 2 illustrates the difference in scale between a MODIS and a Landsat image. A transect site is overlaid to show the extent of field measurements at these scales. A Landsat-derived fractional cover product is also shown.

Site selection

A national sampling strategy has been developed to prioritise where to locate sites for fractional ground cover mapping (Malthus et al. in preparation). It recommends that within the extensive grazing systems of the rangelands and the mixed farming or intensive land use zone:

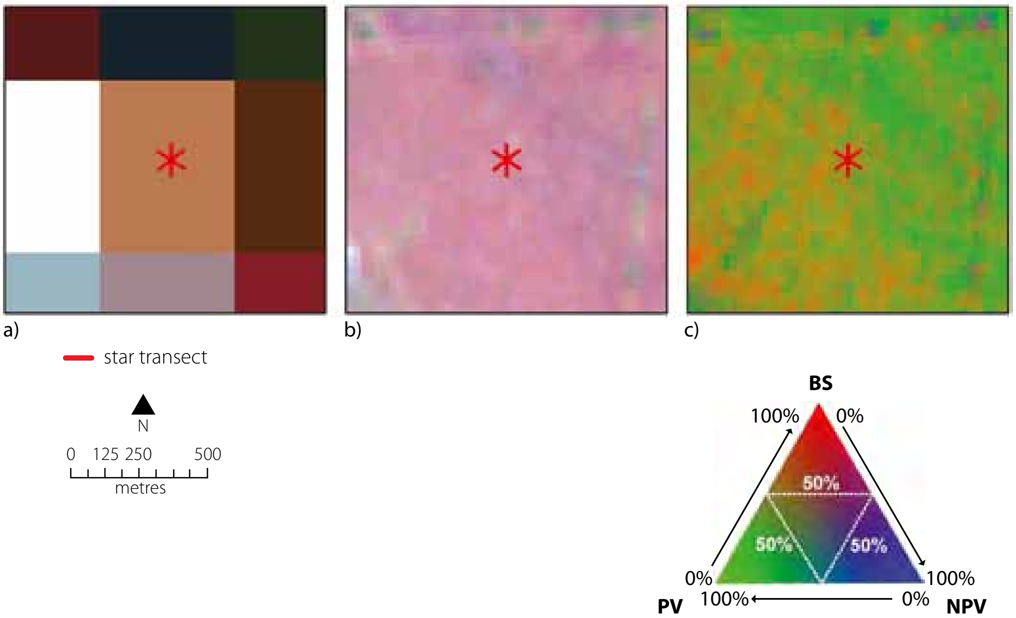
- Sites should be located in areas that are dominated by non-woody vegetation with tree canopy cover less than 20 per cent or 12 per cent foliage projective cover.
- Sites should be homogeneous to minimise within-site variation. Where possible, a homogeneous area greater than 500 x 500 metres is recommended when upscaling field data to MODIS imagery.
- Sample the full range of ground cover from 0 to 100 per cent.
- Sample a range of soil colours and textures.
- Acquire field data within one month of image acquisition.
- The number of sites per Landsat scene should be guided by the complexity of the landscape and vegetation being sampled. A minimum of five sites per Landsat scene is recommended.
- Variability between sites should be captured in the sampling range of the overall sampling strategy.

Other criteria for selecting field sites are:

- Locate the edge of a site at least 100 metres from roads, powerlines or other features not characteristic of the vegetation being measured.
- Locate sites away from water run-on areas. Surface moisture can affect reflectance characteristics of the ground cover fractions.
- Locate sites on level or near-level ground. If selection of a sloped site is unavoidable, avoid western and southern slopes as these are affected by shadow due to winter and morning sun angles.
- For paired sites, locate the sites across fence lines sampling contrasting cover on either side.

The criteria for site selection should be regularly reviewed and the sampling strategy modified to address gaps in the spatial and temporal coverage of sites.

2 Spatial resolution of the MODIS and Landsat sensors

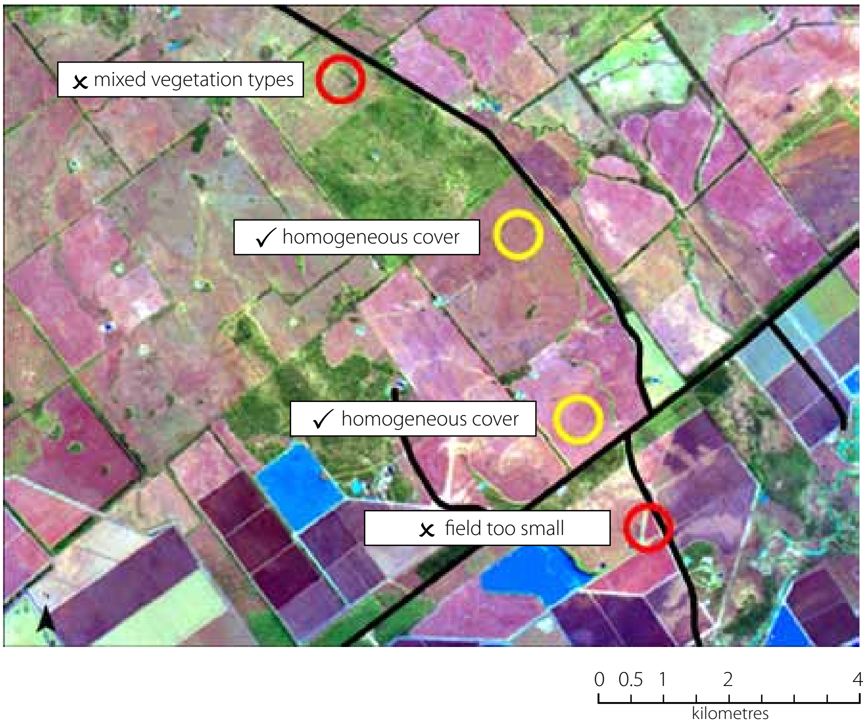


Notes: a) 500-metre MODIS example pixel; b) 30-metre Landsat multispectral image (false colour composite displayed using the shortwave-infrared, near-infrared and green bands); c) a Landsat fractional cover product showing bare soil (BS), photosynthetic vegetation (PV) and non-photosynthetic vegetation (NPV), developed from data collected with the star-transect field method.

Using imagery to locate potential field sites

Site selection can be informed by viewing satellite imagery or aerial photography. Ideally sites should have homogeneous cover. Visual inspection of recent imagery can provide useful contextual information to help identify accessible, spatially and spectrally homogeneous areas with low tree cover. Figure 3 illustrates use of Landsat imagery (RGB bands 5, 4, 2) to identify suitable sites. Two sites are suitable as they have relatively homogeneous cover over the entire site extent, low tree cover and reasonable access. Two other sites are not suitable as they contain mixed land cover features within the site extent.

3 Assessment of field site suitability using Landsat imagery



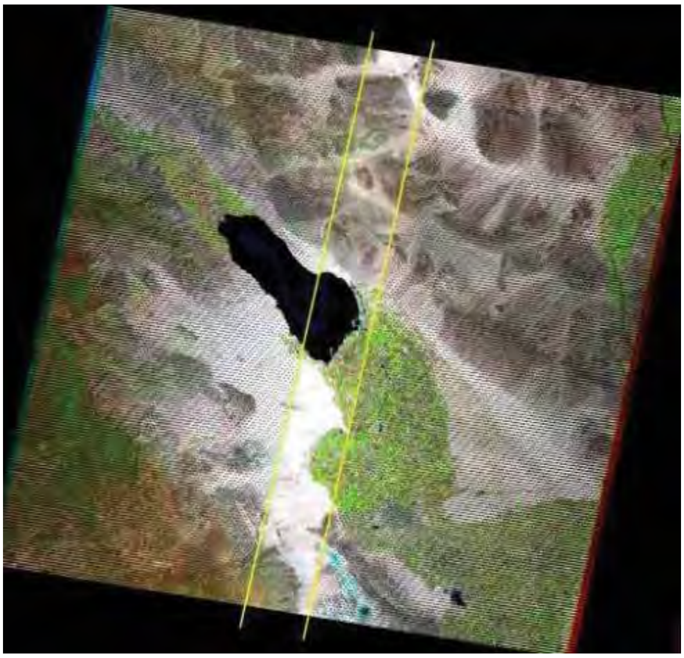
Timing of field data collection

Data collection should be timed to be as near as possible with the satellite overpass and when imagery is cloud free. The season, land management phase and the phenology of the ground cover should also be considered when planning data collection.

Satellite imagery is chosen from either Landsat 5 TM or Landsat 7 ETM+. Both sensors have passed their design life resulting in problems that must be considered when selecting appropriate imagery.

Landsat 5 TM imagery is preferred. The timings of Landsat 5 overpasses are available from the United States Geological Survey (USGS) website (landsat.usgs.gov/tools_L5_acquisition_calendar.php). Overpass does not mean image acquisition. In the southern hemisphere, Landsat 5 TM imagery is not always captured from April through to August. The sensor is switched off to conserve power due to lower solar radiation. The USGS website provides the dates of image acquisition for Landsat 5 (landsat.usgs.gov/sun_angle_limits_landsat_acquisitions.php).

4 Landsat 7 ETM+ with scan line corrector off



Note: The centre portion of the image is the only part not affected.

Use Landsat 7 ETM+ imagery when Landsat 5 TM imagery is not available or is cloud affected. Image acquisition dates are available at the USGS website (landsat.usgs.gov/tools_L7_acquisition_calendar.php). In 2003 the scan line corrector on Landsat 7 failed. The sensor now operates in scan line corrector-off mode. This mode results in large gaps in the imagery with the centre portion the only unaffected data (figure 4). When using Landsat 7 ETM+ imagery for site selection, sites must be located in this unaffected centre portion.

Site description

To adequately describe the site record details of topography, vegetation structure, erosion characteristics, deposited materials, soil and rock colour and tree basal area (chapter 3). These attributes can be used to more fully understand the satellite imagery for the site. For example soil colour will affect the reflectance of the landscape, and may be used to explain the variation in reflectance for a certain ground cover level. Woody vegetation will increase the green fraction of cover estimated from satellite imagery at a site and so it is important to record for use as a modelling parameter. Erosion and microrelief influence the soil surface reflectance by changing the angle at which light is reflected from the surface and can cause shadowing within a pixel when the surface is not smooth. All factors are recorded to provide a more comprehensive understanding of what is occurring at a site and to both inform remote sensing model development and provide land managers with a framework (or possible explanation) for interpreting the mapping developed from remote sensing.

Transect sampling methods

There are many field techniques to measure ground cover. Examples include visual estimates within various sized quadrats and continuous measurement along a downward slope transect. Studies have shown that visual observations generally underestimate ground cover compared to objective field measurements (Murphy & Lodge 2002).

This handbook describes a modified discrete point sampling method for site measurement. This method is recommended as it is quantitative, time-efficient and relatively objective, ensuring repeatability between different operators (Booth et al. 2006). Two different transect layouts for the discrete point sampling method are outlined. The choice of layout is dependent upon the environment or landscape to be sampled.

For most vegetation communities, three transects with 300 observations are recommended (Scarth et al. 2006). Once 300 points have been completed the variation in measured category percentages is minimal, and adding more points does not improve representation of the site (Scarth et al. 2006).

Where vegetation is in rows, as for cropping, two transects with 200 observations are recommended (Schmidt et al. 2010b). The lower complexity of cropping sites requires fewer measurements to capture the variation. Transects are oriented at 45 degrees off-row to ensure adequate sampling both along and across rows.

The default layout is three transects in a star-shape.

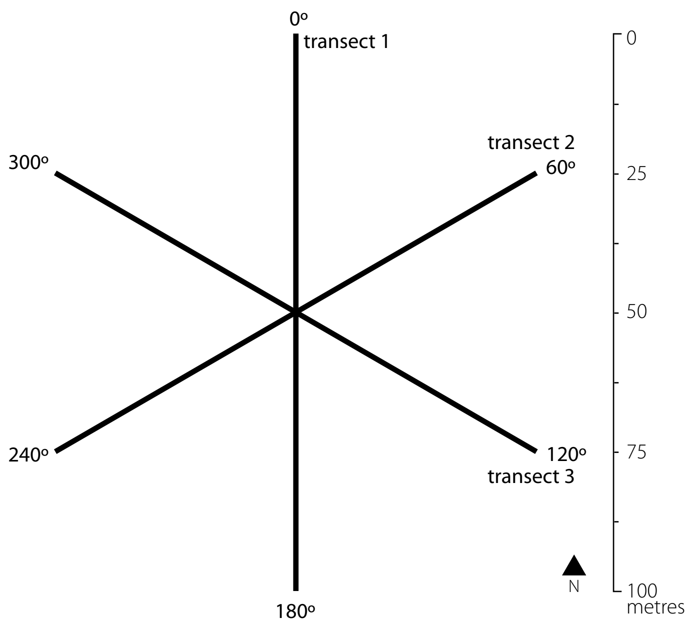
Natural or pastoral environments

In natural vegetation communities, native or improved pasture environments three 100-metre measuring tapes or transects are laid in a star-shape (figure 5). The first is oriented north to south, the second at 60 degrees from north and the third at 120 degrees from north. An observation of the ground cover is made every metre starting at the 1-metre point of each transect. Observations of woody vegetation, categorised as less than 2 metres or greater than 2 metres, are made only when present (Brady et al. 1995). Observations are completed north to south on the first transect, 60 to 240 degrees on the second transect and 120 to 300 degrees on the third transect.

Vegetation in rows

For agricultural crops sown in parallel rows use two transects laid as a cross. Two 100-metre tapes are oriented at 45 degrees across the sowing lines

5 Transect layout in natural or pastoral environments

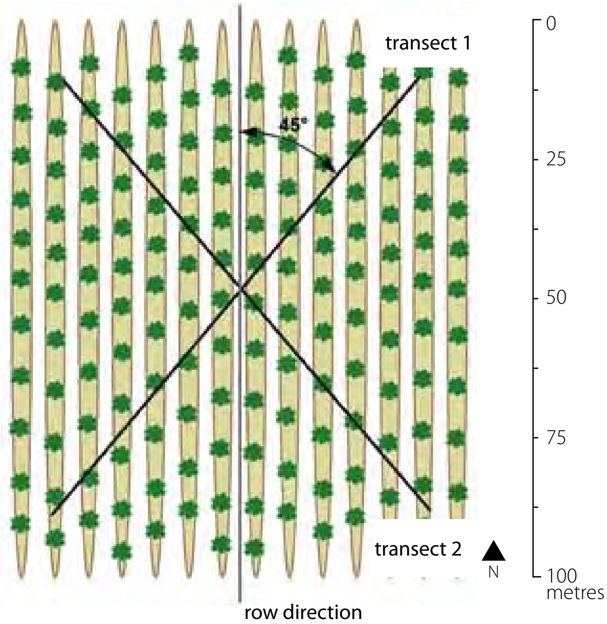


(figure 6). Observations are completed each metre along the transcect closest to north in a clockwise direction, followed by the second transect.

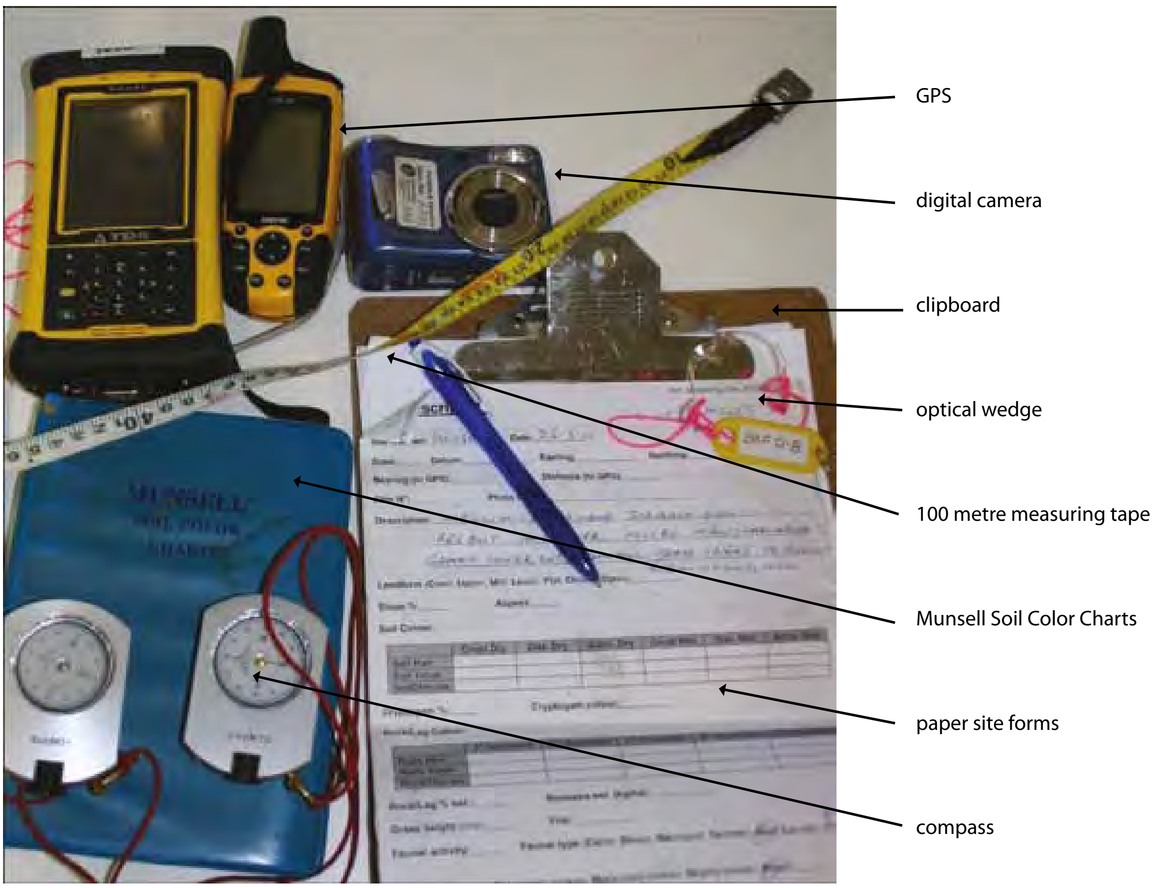
Required field equipment

To undertake the site description and transect measurements some specific field equipment is needed. The field instrumentation chosen must deliver reliable and robust estimates of the ground cover and any woody vegetation present. A field planning and equipment checklist is given in appendix 1. A description of the equipment, its use and specifications are given in appendix 2. Some of the required field equipment is shown in figure 7. Figure 15 shows the device for measuring fractional cover—a densitometer and laser pointer attached to a telescopic pole.

6 Transect layout in vegetation in rows, such as agricultural crops



7 Some required field equipment



3 Site description

Site description attributes for soils and landforms follow the *Australian soil and land survey field handbook* (NCST 2009), in particular McDonald et al. (2009). For rangelands sites, Tongway & Hindley (1995) provide photographs of many land surface attributes. Attributes for site description are recorded in electronic (www.abares.gov.au/landuse/) or hard copy form (appendix 3).

Basic site description

Location description

A description of the location of the site.

Example: 60 km west of Longreach, second turn left after the bridge crossing 'Dead horse creek', 4.3 km off the main road.

Basic site description

A general description of the main attributes of the site.

Example: Grazing paddock, undulating low hills with low ground cover and scattered trees.

Site identifier

A unique reference identifier (ID) for the site given as two or three letters for state abbreviation, and three digits for site number (STATEsitenumber).

Example: SA001

Protocol

The data standard used for field data collection. Data collected as described in this handbook has the protocol of 'Ground cover monitoring'.

Revisit

Indicate if the site has already been visited on a different date and sampled with the same protocol.

Field observers

List the names of all field operators making the observations.

Date

The date the site was completed in the format day, month and year (dd/mm/yyyy).

Time

The time the field site was started, in 24-hour time.

Position

The geographical position of the centre of the site as measured with a global positioning system (GPS).

Bearings

The bearing or angle in degrees from north along which transects are placed. The bearing is always the same when using the three star-shaped transects—transect 1: 0°; transect 2: 60°; transect 3: 120° (figure 5). The bearings will differ when using the two cross-shaped transects for sites with vegetation in rows, such as agricultural crops (figure 6).

Landholder consent

Obtain landholder consent for release of site data where it has been collected on private or leasehold land.

Slope and aspect

The slope of the site measured as a percentage (0–100 per cent) and aspect measured in degrees (0–360°). Slope is measured using a clinometer (figure 16a). Aspect is measured by obtaining a compass bearing for the horizontal direction in which the slope faces and rounding to the nearest 10°.

Land use

Land use is recorded using the Australian Land Use and Management (ALUM) classification, version 7 (ABARES 2011). Tertiary classes (appendix 4) are the minimum requirement, with crops ideally recorded to commodity level, such as 3.3.1 Cereals, wheat (ABARES 2011 pp. 115–20).

Cropping or non-cropping

Record if the site is cropped. This provides a check for the transect method used.

Plant growth stage

Note the growth stage that best describes most plants observed. Growth stages are:

- Establishment: germination or seedling emergence.
- Immature or growing: shoot and leaf development or regrowth if plant has been cut or grazed.
- Mature: plants at or close to mature height, flowering or seed development is occurring.
- Senescence or residue: seed drop has occurred and plant is starting to die off, includes standing stubble (that is, stubble attached to the ground).
- None: no growing plants present, includes unattached stubble or litter on ground.

Management phase

The current management phase for the vegetation present, including litter (interpreted with growth stage):

- Abandoned: land no longer used to grow pastures or crops; weeds may dominate or previous cropping species may be present.
- Baled: plants or their residue gathered into bales; for example, for hay, silage or straw.
- Burnt: plants or their residue (attached or unattached) have been burnt.
- Cultivated: soil has been tilled; for example, in preparation for planting or incorporation of stubble.
- Grazed: evidence of animals grazing.
- Incorporated: plants or their residue have been ploughed into the soil; some may remain on the surface.
- Mulched: plants or their residue has been mulched and left on the surface.
- Sprayed: pasture or weeds killed with herbicide for sowing of next crop.
- Standing or none: plants are growing or senescent, or when harvested the stubble has been left attached.
- Other: management phase not listed.

The plant growth stage and management phase have been informed by the provisional categories proposed for national standards for roadside erosion surveys (Forward 2009).

Site photos

A minimum of seven photos are taken at each site in natural or pastoral environments. A minimum of five photos are taken where the site is in vegetation in rows (cropping). The first photo is taken at breast height (1.3 metres) directly over the site centre looking down at the ground. The remaining photos are taken standing at the site centre looking out along each transect tape, starting at north and working around in a clockwise direction. Focus the camera on the vegetation cover at the transect end and take the photo in 'landscape' mode.

Name photos using the following nomenclature:

- SiteID_G1.jpg for the first centre photo of the ground (G).
- SiteID_L1 – SiteID_L6.jpg for the six photos (or four for a cropping site) taken along the transect lines (L).
- Example: SA001_G1.jpg; SA001_L1.jpg; SA001_L6.jpg

Field spectra collected

Record whether spectra measurements are taken for the site. A spectroradiometer is used to record the spectral reflectance of surface features. These readings can be done in the field or under controlled conditions in a laboratory. This is an optional attribute taken if spectral signature analysis at the site is required.

Vegetation description

Biomass estimate

The dry weight of above-ground plant material at the site is estimated visually. Only standing (attached) non-woody ground cover is considered. Biomass varies between grass species and paddock condition, with annuals generally lighter than perennials. With training, field operators can become skilled in estimating biomass. This involves weighing representative units of a plant and establishing an 'eye' for different amounts of biomass. An alternative is to use photo reference guides, or photo standards, with measured biomass indicated (for example appendix 5). Source photo reference guides specific to the site's locality and/or pasture or crop type.

Where time and resources permit, biomass can be measured quantitatively by cutting the standing biomass within quadrats (appendix 6).

Biomass is measured in kilograms per hectare (kg/ha).

Average non-woody vegetation height

Record the average grass or crop height at the site in metres to two decimal places.

Fire occurrence

Visual assessment of occurrence of fire at the site including severity and estimated time since fire occurred.

- No evidence of fire (0)
- Minor burn (1): less than 5 per cent of site affected or fire occurred more than 3 years ago
- Recent or major burn (2): more than 5 per cent of site affected or fire occurred less than 3 years ago.

Perennial vegetation percentage

The percentage of grass cover at the site with a lifespan extending over more than one growing season.

Categories are: 0–5 per cent, 6–25 per cent, 26–50 per cent, 51–75 per cent and 76–100 per cent.

Average woody vegetation height

The average height (in metres to one decimal place) of the tallest stratum either estimated or measured using a clinometer (figure 16b).

Vegetation description by structural formation

The scientific name and percentage occurrence, by biomass, of the three dominant species for the categories woody vegetation greater than 2 metres, woody vegetation less than 2 metres, and ground cover (non-woody vegetation). Avoid using common names for vegetation species.

Dominance by biomass is not species abundance. For example at a hypothetical site the tallest stratum may be dominated by three species: a few large, mature *Eucalyptus cambageana* trees (50 per cent biomass), many small-stemmed, immature *Acacia cambageii* trees (30 per cent biomass) and a few immature *Eucalyptus populnea* trees (20 per cent biomass). Although *A. cambageii* has a higher abundance, *E. cambageana* has the higher biomass, and is assigned as the first dominant species, followed by *A. cambageii* and *E. populnea*.

Tree basal area

Tree basal area (TBA) is the cross-section of a tree trunk measured at breast height (1.3 metres) over bark (NSW DECCW 2010). If trees are present at the site, TBA is measured at 7 points on the transects using an optical wedge prism (appendix 2) or Haglöf Factor Gauge (appendix 2). The first reading is taken at the site centre and the remainder at 25 metres on each transect arm, starting at north and proceeding in a clockwise direction (figure 8). The number of live and dead trees counted as being 'in' is recorded. The prism factor, observer's initials, number of live trees and number of dead trees is recorded for each measurement. Only the average live TBA for the site is calculated using the equation:

$$LTBA = \frac{\sum F(L)}{N} \tag{1}$$

where $LTBA$ is live tree basal area in m^2/ha, F is the prism factor, L is the number of live trees, and N is the number of measurements (in this case $N = 7$).

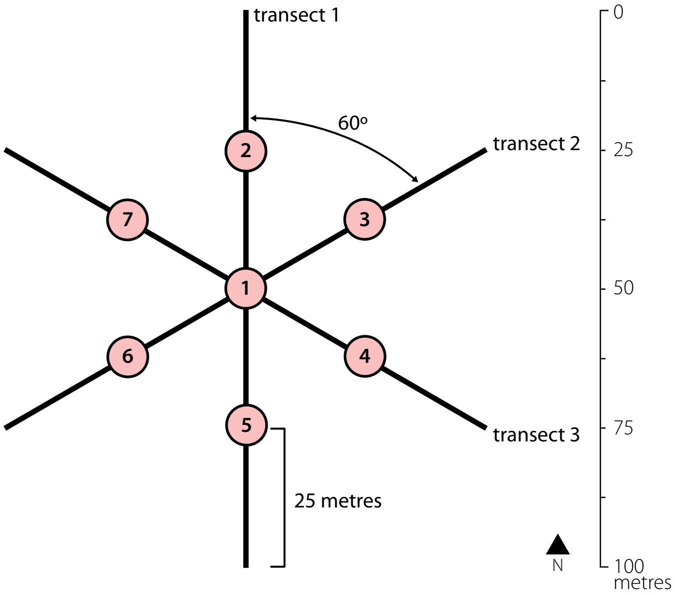
If standing TBA is required use the equation:

$$STBA = \frac{\sum F(L + D)}{N} \tag{2}$$

where $STBA$ is standing tree basal area in m^2/ha, F is the prism factor, L is the number of live trees, D is the number of dead trees and N is the number of measurements (in this case $N = 7$).

Field operators should ensure they do not differ in their TBA measurements between operators. Take measurements at several sites using a strict blind testing procedure to assess if one operator is systematically measuring more or less. Bias can be introduced by, for example, using the wrong basal area factor, not measuring at breast height (1.3 metres) and counting borderline trees as 'in' or 'out' (figure 17).

8 Positioning of tree basal area measurements on transects



Land surface

Erosion

Record the presence and form of erosion occurring at the site. The descriptors refer to accelerated erosion rather than natural erosion. The categories of the *Australian soil and land survey field handbook* (NCST 2009 pp. 133–37) are used.

State of erosion

- None (N): no erosion evident at site.
- Active (A): sediment movement evident and/or eroded area is bare of vegetation.
- Stabilised (S): sediment movement not evident and/or eroded area has revegetated.
- Partly stabilised (P): some sediment movement and stabilisation evident.

Wind erosion

- No wind erosion (0).
- Minor or present (1): some loss of surface.
- Moderate (2): most or the entire surface has been removed leaving soft or loose material.
- Severe (3): most or all of surface has been removed leaving hard material.
- Very severe (4): deeper layers exposed leaving hard material (such as subsoil, weathered rock or pans).

Scald erosion

Scald erosion is removal of surface soil by water and/or wind often exposing clayey subsoil which is devoid of vegetation and relatively impermeable to water. Scalds are most common in arid or semi-arid lands.

- No scalding (0).
- Minor (1): less than 5 per cent of site scalded.
- Moderate (2): 5–50 per cent of site scalded.
- Severe (3): more than 50 per cent of site scalded.

Water erosion

Where water erosion is occurring the severity is attributed. Three main types of water erosion occur: sheet, rill and gully erosion (figure 9).

Sheet erosion

Sheet erosion is the relatively uniform removal of soil from an area without channels developing. Indicators of sheet erosion include soil deposits in downslope sediment traps, such as fence lines or dams, root exposure or exposure of subsoils.

- No sheet erosion (0).
- Minor (1): small amount of sediment deposited downslope. Often difficult to assess due to cultivation, revegetation, etc.
- Moderate (2): partial exposure of roots, moderate soil deposits in downslope sediment traps.
- Severe (3): loss of surface horizons, exposure of subsoils, substantial sediment deposited downhill.

Rill erosion

A rill is a small channel less than 0.3 metres deep.

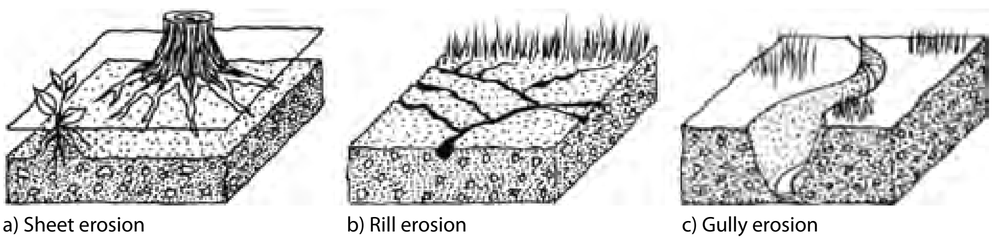
- No rill erosion (0).
- Minor (1): occasional rills.
- Moderate (2): common rills.
- Severe (3): numerous rills forming corrugated ground surface.

Gully erosion

A gully is a channel more than 0.3 metres deep. Where possible, field sites should be chosen to avoid large gullies.

- No gully erosion (0).
- Minor (1): isolated gullies.
- Moderate (2): gullies restricted to drainage lines.
- Severe (3): gullies branch away from primary drainage lines.

9 Examples of sheet erosion, rill erosion and gully erosion



Source: Landcare South Africa 1999, *Soil Erosion*, National Department of Agriculture, South Africa, available at www.nda.agric.za/docs/erosion/erosion.htm

Deposited materials

Material deposited on the soil surface. Classified as:

- Sand: less than 2 mm.
- Gravel: 2–60 mm.
- Stones: more than 60 mm.

The abundance of sand, gravel or stones is estimated by eye using the charts in NCST (2009 pp. 141).

- None (0).
- Very few (1): less than 2 per cent of site.
- Few (2): 2–10 per cent of site.
- Common (3): 10–20 per cent of site.
- Many (4): 20–50 per cent of site.
- Abundant (5): 50–90 per cent of site.
- Very abundant (6): more than 90 per cent of site.

Microrelief

Microrelief refers to relief up to a few metres within the entire 100 × 100 metre field site. The vertical interval between the base and crest is estimated, as well as the horizontal distance between crests. In natural settings this refers to features such as gilgai, or hummocking while in cropped areas it refers to rows. This category is a simplified version of the microrelief category in NCST (2009 pp. 129–33).

- Smooth (0): less than 3 mm variations.
- Mounds (M): convex, includes gilgai and hummocks.
- Depressions (D): concave.
- Cropping rows or furrows (C).

Biotic microrelief

Biotic microrelief is relief caused by biotic agents (NCST 2009 pp. 131) such as termite mounds, rabbit warrens, wombat burrows, pig wallows, constructed terraces, stump holes, vegetation mounds. Specify up to three biotic agents.

- Animal (N): horse (NH), sheep (NS), cow (NC), goat (NG), pig (NP), macropod (NM), camel (NL), rabbit (NR).
- Human (M).
- Bird (B).
- Termite (T).
- Ant (A).
- Vegetation (V).
- Other (O).

Soil description

Surface condition when dry

The characteristic appearance of dry surface soil (NCST 2009 pp. 189–91). Surface conditions are not necessarily mutually exclusive. Record up to three conditions:

- Cracking (G): cracks at least 5 mm wide up to the surface or any plough layer.
- Self-mulching (M): strongly pedal loose surface mulch forms on wetting and drying. Peds commonly less than 5 mm.
- Loose (L): less than two-thirds of the soil mass stays together at any given moisture state. Surface easily disturbed by pressure of forefinger.
- Soft (S): at least two-thirds of the soil matter remains united unless force is applied. Surface easily disturbed by pressure of forefingers.
- Firm (F): less than two-thirds of the soil mass stays together at any given moisture state. Surface disturbed or indented by moderate pressure of forefinger.
- Hard setting (H): compact hard apedal condition forms on drying but softens on wetting. Material is hard below any surface crust and is not disturbed or indented by pressure of forefinger.

- Surface crust (C): distinct surface layer which is hard and brittle when dry and not readily separated from underlying material. Can be a few millimetres to a few tens of millimetres thick.
- Surface flake (X): thin massive surface layer which on drying easily separates from soil below. Usually less than 10 mm thick.
- Cryptogam surface (Y): thin, more or less continuous crust of biological stabilised soil material usually due to algae, liverworts and mosses.
- Trampled (T): hoofed animals have extensively trampled soil under dry conditions.
- Poached (P): soil has been extensively trampled under wet conditions by hoofed animals.
- Recently cultivated (R): effect of cultivation is obvious.
- Saline (S): surface has visible salt, or salinity is evident from the absence or nature of the vegetation or from soil consistency.
- Other (O).

Soil strength

Strength of soil is the resistance to breaking or deformation. Determined by the force just sufficient to break or deform a 20 mm diameter piece of soil when squeezed between thumb and forefinger or by standing and using body weight on a hard flat surface (NCST 2009 p. 187).

- Loose (0): no force required. Separate particles such as loose sands.
- Very weak (1): very small force using thumb and forefinger, almost no force.
- Weak (2): small but significant force using thumb and forefinger.
- Firm (3): moderate or firm force using thumb and forefinger.
- Very firm (4): strong force but can be deformed using thumb and forefinger.
- Strong (5): cannot be deformed by thumb and forefinger, crushes underfoot with small force.
- Very strong (6): crushes underfoot with full body weight.
- Rigid (7): cannot be crushed underfoot when using full body weight.

Surface cracks

The widths of planar voids on the soil surface are recorded except for self-mulching or loose soils (NCST 2009 p. 184).

- Fine (1): less than 5 mm.
- Medium (2): 5–10 mm.
- Coarse (3): 10–20 mm.
- Very coarse (4): 20–50 mm.
- Extremely coarse (5): more than 50 mm.

Soil colour

Use Munsell Soil Color Charts to record soil colour as a combination of hue, value and chroma, for example 5YR5/3 (figure 19; NCST 2009 p. 159). Record the wet and dry colour of the soil crust and the disturbed soil.

Cryptogam cover and colour

The percentage of the soil surface covered with cryptogam is visually estimated at each site using the charts in NCST (2009 p. 141) and the abundance categories for deposited materials (see 'Deposited materials'). A qualitative colour description (such as dark green, bright green or black) and whether the cryptogam is wet or dry is also recorded to provide an indicator of photosynthetic activity. The effect of cryptogamic crust on the spectral reflectance of soil is given in appendix 7.

Rock colour, abundance and size

Rock is defined as larger than 20 mm and lag as a particle that can be seen as a single grain (approximately 2 mm up to 20 mm). Record the first three dominant rock/lag cover colour readings at each site using the Munsell Soil Color Charts (appendix 2). The percentage of rock/lag cover is estimated by eye using the charts in NCST (2009 p. 141) and the abundance categories for deposited materials. These coarse fragments can be of any shape. The average maximum dimension of fragments is used to determine the class interval (NCST 2009 p. 140):

- Fine gravelly (1): 2–6 mm.
- Medium gravelly (2): 6–20 mm.
- Coarse gravelly (3): 20–60 mm.
- Cobbly (4): 60–200 mm.
- Stony (5): 200–600 mm.
- Bouldery (6): 600–2000 mm.
- Large boulders (7): greater than 2000 mm.

4 Transect methodology

Transect setup

Two different transect setups are used depending on whether the field site is in a natural environment, such as in the rangelands, native or improved pasture, or the vegetation is in distinct rows, such as under cropping. General design details are discussed in 'Transect sampling methods' (chapter 2). Specific steps to set up transects and complete transect measurements are listed below. Figure 5 and figure 6 show a schematic representation of the transect layouts.

Natural or pastoral environments

The steps to completing a transect at a natural or pasture site are:

1. Hammer stake into ground at centre of site.
2. Use compass to find 0° bearing and run tape out at this bearing until the 50-metre mark is level with the centre stake.
3. Return to centre and twist tape once around the stake to secure in place. Run remaining 50 metres of tape out at 180°.
4. Repeat for the second and third tapes, at 60°/240° and 120°/300° respectively.
5. Average GPS readings to obtain site centre coordinates.
6. Complete site description details (chapter 3).
7. Complete transect measurements starting at the 1-metre mark on the tape.

Vegetation in rows

The steps to completing a transect at a cropping site with distinct rows are:

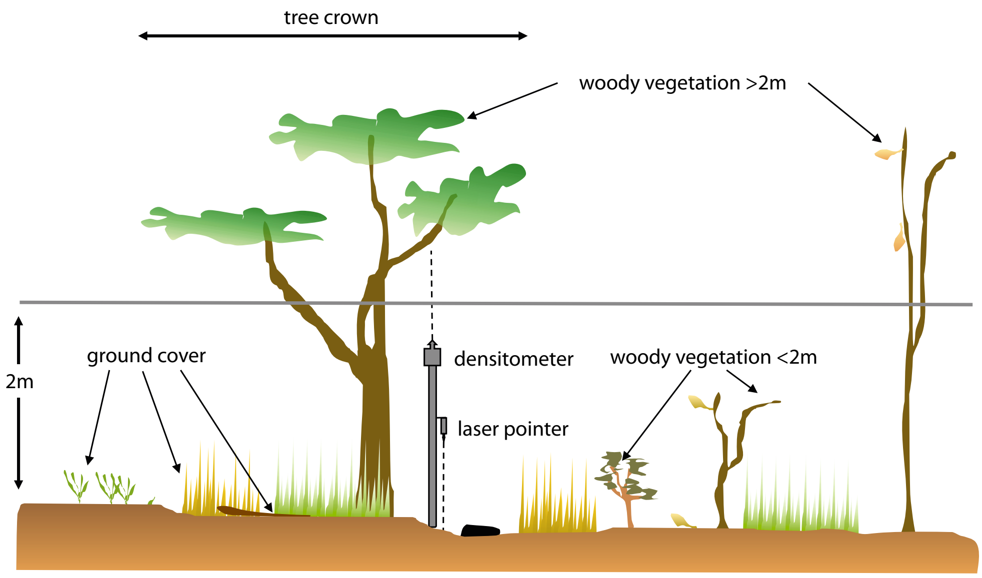
1. Hammer stake into ground at centre of site.
2. Determine row direction (e.g. 30°).
3. Determine bearing 45° off-row direction, which is closest to north in the clockwise direction (e.g. 75°).
4. Use compass to find bearing and run tape out at this bearing until the 50-metre mark is level with the centre stake.
5. Return to centre, and twist tape once around the stake to secure in place. Run remaining 50 metres of tape out at 180° to original bearing (e.g. 255°).
6. For the second tape determine bearing 90° in the clockwise direction to the bearing for transect 1 (e.g. 75° + 90° = 165°), and run tape out until the 50-metre mark is level with the centre stake.
7. Return to the centre and run remaining 50 metres of tape out at 180° to original bearing (e.g. 345°).
8. Average GPS readings to obtain site centre coordinates.
9. Complete site description details (chapter 3).
10. Complete transect measurements starting at the 1-metre mark on the tape.

Transect measurements

Definitions of vegetation categories

Fractional cover measurements are recorded in three vegetation categories: non-woody or ground cover; woody less than 2 metres; and woody greater than 2 metres (figure 10). The ground layer is observed by looking downwards, while woody vegetation is observed by looking upwards, or downwards where vegetation is less than observer's height.

10 The vegetation categories measured



Ground cover

Ground cover includes non-woody vegetation (such as grasses, forbs and herbs), litter, cryptogams, soil and rock. There is no height restriction for non-woody vegetation. Grasses taller than 2 metres, as in some parts of northern Australia, are included in the ground cover category. Observations in this category are recorded as:

- Crust—the hard surface layer of soil.
- Disturbed soil—cracks in a soil crust, ant nests or other disturbances in the natural surface, such as by animal hoof prints. In ploughed agricultural sites most soil recordings will be disturbed.
- Rock/lag—rock includes all stones and rock material greater than 20 mm. Lag includes all single grains that can be differentiated by the naked eye, approximately 2 mm to 20 mm.
- Cryptogam—a biological crust composed of non-vascular plants, such as algae, liverworts and mosses.
- Green leaf—a leaf with green pigmentation (one that is actively photosynthesising) attached to the plant. Sometimes the leaf in this state may appear more yellow than green. In this case make a judgement call as to whether to place it in the green or dry category.
- Dry leaf—a leaf with non-green pigmentation (one that is not actively photosynthesising). This can include senescent (alive) vegetation as well as dead vegetation. It must be attached to the ground or plant.
- Litter—dead plant material that is not attached to the ground. Includes branches, leaves or fallen tree trunks.

Woody vegetation less than 2 metres

All vegetation with a woody component and a height of less than 2 metres are generally shrubs, including chenopods, and small trees. Observations in this category are recorded as:

- Green leaf—a green leaf attached to a plant.
- Dry leaf—a dead or dry leaf attached to a plant.
- Branch—woody component of the plant (branch or trunk).

Woody vegetation greater than 2 metres

All woody vegetation with a height of 2 or more metres are generally tall shrubs and trees. Observations in this category are recorded as:

- In crown—the vertically projected perimeter of all foliage and branches of the plant. This is recorded for live plants only.
- Green leaf—a green leaf attached to a plant that is greater than 2 metres in height.
- Dry leaf—a dead or dry leaf attached to a plant that is greater than 2 metres in height.
- Branch—woody component of the plant (branch or trunk).

Transect measurements

Observations are made at each metre along each transect tape, starting at the 1-metre mark using the cover measurement device (figure 15). A measurement is always recorded for the ground cover category. Measurements are only made for the other two categories where these elements are observed. Figure 11 shows two field operators completing transect measurements. At least two field operators are needed: one as the observer and 'calling' the measurements for the other to record. Data is entered into the transect form with an observation recorded as a '1' at each intercept (figure 20).

11 Field operators using densitometer and laser pointer attached to telescopic pole measuring along a transect

Measuring ground cover:

- Position the pole with the laser pointer attached vertically next to the metre mark on the measuring tape. Use level in densitometer to ensure pole is vertical.
- Press the power button of the laser pointer.
- Record the first intercept of the laser beam when looking downwards in the appropriate category (figure 12).

12 Ground cover observations at a cropping site


a) Litter at 4 metres on the tape


b) Crust at 5 metres on the tape

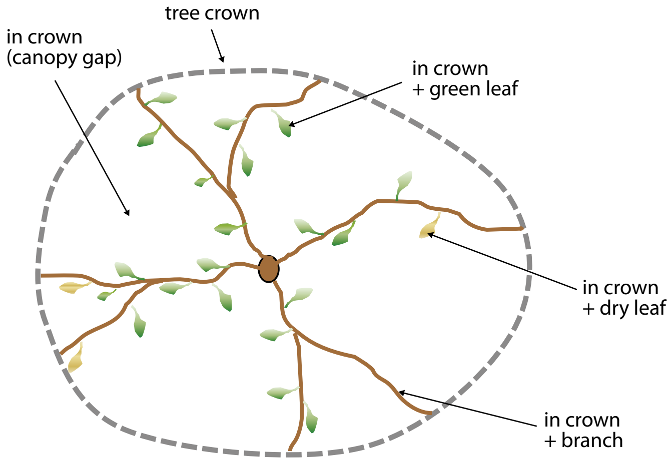
Measuring woody vegetation less than 2 metres in height:

- Maintain the pole in the same position as where the ground cover measurement was taken.
- Determine if there is an intercept of woody vegetation of less than 2 metres with the pole directly above the point recorded for the ground cover.
- Record the intercept in the appropriate category—green leaf, dry leaf, branch.

Measuring woody vegetation taller than 2 metres:

- Maintain the pole and densitometer in the same position as used for the ground cover and woody vegetation of less than 2 metres measurements.
- The observer checks visually to determine if they are within a live or dead tree crown. If it is difficult to determine if the tree is completely dead, assume it is alive.
- When within a tree crown the densitometer is positioned vertically using the spirit levels and the observer peers through the mirror sight to determine the first intercept directly above the viewpoint.
- Within a live tree crown, the first intercept is recorded in the appropriate category—'in crown' for canopy gap (sky visible) or 'in crown' and green leaf or dry leaf or branch (figure 13).
- If the tree is completely dead, branch or dry leaf is recorded and no reading made for 'in crown'.

13 Recorded observations within the vertical projection of a live tree crown



Methods for calculating the ground cover fractional components at a site are given in appendix 8. These fractional components are calculated automatically in the electronic transect data entry sheet.

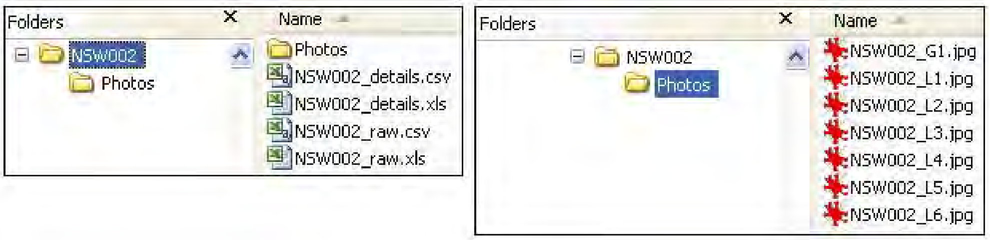
5 Field data storage

Post-field data processing

The collected field data is entered into two spreadsheets—the site description form and the transect form. Store the spreadsheets and field photography consistently. This is critical for data consistency and database management. The structure in figure 14 is recommended. All data are saved in the Site ID folder. Photographs are stored in the photos sub-folder using the specified photo names (see 'Site photos' chapter 3). The 'details' file contains the site description, and the 'transect' file the observations. This file structure ensures all relevant data for a given site on a given date are stored together.

For easy upload into a spatial database save the Microsoft Excel file site_transect.xls as a .csv file and the 'output' sheet in the site_details.xls file as a .csv file. This gives the file structure shown in figure 14. Write files to CD or DVD and mail to ABARES (see 'Further information'). Keep a backup copy on a local server.

14 File structure for importing into the database



a) field site folder b) field site photo folder

Database storage

ACLUMP partners collecting field data during 2010–13 as part of the national network of ground cover sites provide their data to ABARES. The data are stored in a central database (Rickards et al. 2011) and used for calibration and validation of the fractional cover remotely sensed products. The data are stored in their raw form—actual transect intercepts—with a summary table detailing the proportion of intercepts for each category. An observation key is automatically generated to provide a unique site identifier. This key contains the location in latitude and longitude and the date and time the field work was completed.

Appendix 1 Field checklist

Pre-field:

- [ ] Determine potentially suitable sites. Sites should be easily accessible and meet the selection criteria size and homogeneity requirements.
- [ ] Check growth phase or timing of land management practice is suitable.
- [ ] Determine if a recent Landsat image is available over the site.
- [ ] Arrange access to sites with landholders.
- [ ] Organise staff availability, vehicles, equipment and accommodation.

Equipment:

- [ ] 3 × 100 m wind-up measuring tapes
- [ ] Timber stake/star picket for anchoring tapes at site centre
- [ ] Hammer
- [ ] Compass
- [ ] GPS (differential GPS preferred)
- [ ] Densitometer
- [ ] Telescopic pole to mount densitometer
- [ ] Laser pointer
- [ ] Tape or other device to attach densitometer to pole
- [ ] Clinometer
- [ ] Optical wedge prisms (factors 1.0 and 2.0)
- [ ] Munsell Soil Color Charts
- [ ] Water bottle (for wet soil observations)
- [ ] Digital camera
- [ ] Vegetation identification books (optional)
- [ ] Biomass photo standards (where available)
- [ ] Clipboard
- [ ] Paper field data collection forms (for each site)
- [ ] Notebook computer / PDA (if using electronic forms)
- [ ] Electronic site forms (1 × site description; 1 × transect entry)
- [ ] Flagging tape (optional)
- [ ] Bag/box to carry field equipment into site

Note: Paper forms should still be taken on field work as a backup, even if using electronic data entry forms. This will allow data to be collected in the case of computer and/or battery problems.

Post-field:

- [ ] Collate field data, photos and enter in electronic field data forms (if not already done).
- [ ] Complete post-field editing of data and send to ABARES.

Appendix 2 Field equipment

Equipment description and specifications

Laying transects

Three 100-metre tapes with 1-metre markings are needed to perform the field measurements. The tapes are oriented as in figure 5 or figure 6. A short star picket or wooden stake hammered securely into position anchors the centre of the tapes. A compass is used for tape placement. The tapes should be placed on the ground beneath vegetation, be straight and follow a constant bearing. The operator should sight from the centre of the tapes along the bearing and choose a landmark, such as a tree, to walk towards. Re-check the bearing at least every 25 metres. Avoid trampling along the transects where observations will be made. Refer to 'Transect methodology' (chapter 4) for more details.

Global positioning system

Use a differential GPS with an accuracy of 1 metre or less to record the coordinates of the centre point of the transects. This also enables accurate relocation of a site for repeat sampling without the need for permanent site markings (Scarth et al. 2006). If a non-differential, handheld GPS is used average the coordinates of the centre point for at least 5 minutes.

Specifications for the GPS recording are:

- Zone: as per MGA94 or UTM.
- Datum: WGS84 or GDA94.
- Projection: MGA94 or UTM.
- Units: metres.
- Easting: to one decimal place.
- Northing: to one decimal place.

Cover measurement device

The device for field sampling has three components:

- a densitometer for measuring woody vegetation
- a laser pointer for measuring the ground cover and low woody vegetation
- a telescopic pole to which the laser pointer and densitometer are attached.

The densitometer and laser pointer can be attached to the telescopic pole using tape. For a more robust solution a mount can be created for the densitometer using PVC piping (figure 15c).

The densitometer is used to observe the vertical projection of woody vegetation canopy cover along a transect. It has a sighting mirror and levelling vials which allow the operator to see what is directly overhead (figure 15b). At each sampling point the densitometer is levelled and the operator peers at the mirror sight to determine if the point in the centre of the densitometer is intercepted by the canopy. The densitometer is mounted on a telescopic pole to allow the user to adjust the height level. After completing a field site the number of points with canopy coverage can be divided by the total number of points sampled. The result is the percentage of canopy coverage for that site (GRS 2008).

A standard laser pointer is used for taking objective ground cover measurements. The laser pointer is attached to the telescopic pole upon which the densitometer is mounted, pointing downward. The laser pointer should be within easy reach of the observer, about 0.8 metres off the ground, with the laser beam pointing down about 30–50 mm from the pole so the ground cover to be measured is not crushed by the pole. The observation is taken by reading the first intercept of the laser beam with the ground cover component.

15 Cover measurement device

a) b) c)

Notes: a) Laser pointer and densitometer mounted on a telescopic pole; b) Horizontal and vertical levels used to position the densitometer; c) Densitometer mounted on a telescopic pole (side view).

Clinometer

A clinometer measures inclination or slope. To measure hill slope an observer stands facing up the slope, and levels the sight of the clinometer at a point in the distance which is approximately the same height as their own height (figure 16a). The slope is recorded as a percentage (0–100 per cent).

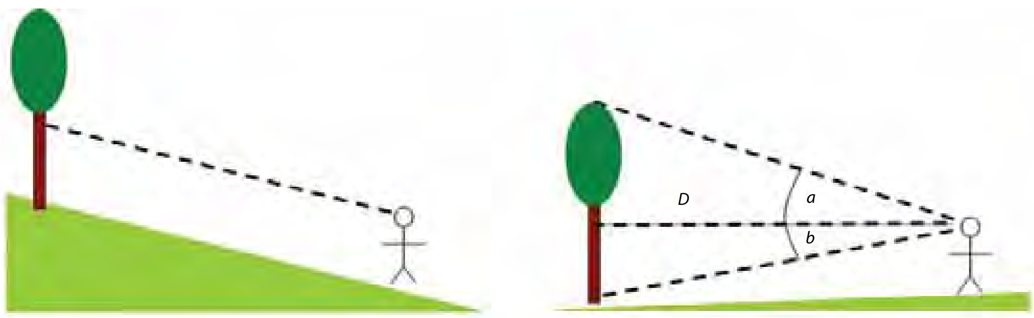
A clinometer reading can also be used to estimate tree height. The observer stands at a distance from the tree where the top of the crown can be easily viewed. The distance from the tree base (D) is recorded using a measuring tape. The observer takes a reading using the clinometer to record the angle to the crown of the tree (a) and the base of the tree (b) in degrees (figure 16b). The height of the tree (H) is then calculated as:

$$H = (A \times D) + (B \times D) = (A + B) \times D \qquad (3)$$

where $A = \tan a$ and $B = \tan b$

A and B are added together to account for the observer's height. Methods for measuring tree height using a clinometer are explained in NSW DECC (2007).

16 Using a clinometer to measure hill slope and tree height



a) Measuring hill slope

b) Measuring tree height

Optical wedge prisms

An optical wedge prism can be used to quickly estimate tree basal area per hectare (Mannel et al. 2006). Basal area defines the area of a given section of land that is occupied by the cross-section of tree trunks and stems at their base. This is measured at a person's breast height (approximately 1.3 metres) and includes the entire diameter of every tree, including the bark. Measurements are used to examine a forest's productivity and growth rate (Mannel et al. 2006). Basal area is generally expressed in square metres per hectare (m^2/ha).

The appropriate prism factor to use at a site gives a plot radius (the radius of the area that will be sampled) of approximately 15–20 metres. Plot radius is determined by the average tree diameter and prism factor using the formula:

$$R = \frac{D}{2\sqrt{BAF}} \tag{4}$$

where R is the plot radius, D is the tree diameter and BAF is the basal area factor.

Table 1 shows the plot radii for a number of BAFs and tree diameters, with the appropriate BAF for a certain tree diameter highlighted. At a site with an average tree diameter of 0.3 metres use a prism factor of 0.6–1.0, whereas a site with an average tree diameter of 0.1 metres use a prism factor of 0.1.

In Australia only optical wedge prisms with a basal area factor of 1.0 or greater are available from suppliers. Count all trees when using the wedge prism at sites with an average tree diameter of less than 0.3 metres, as this BAF is not the most appropriate for trees in this size range. An alternative is to use a Haglöf Factor Gauge or to make a gauge based on a standardised template.

To use the optical wedge prism the observer holds it at arm's length and looks through the prism at the tree being counted. If the tree trunk appears to overlap the tree viewed without the wedge prism the tree is counted (figure 17a). If the trunk does not overlap the tree is not counted (figure 17b). Where the trunk just touches, the tree is given a 1/2 count (figure 17c). With the prism kept at a fixed point, the observer rotates 360 degrees around the prism and counts all trees that are 'in'. The basal area is the number of 'in trees' multiplied by the basal area factor of the wedge prism or gauge. To calculate the site tree basal area 7 readings are taken and averaged (see 'Tree basal area' chapter 3).

Table 1 Plot radii (metres) as function of prism factor and tree diameter

Basal Area Factor	Tree diameter (metres)										
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.5
0.05	22	45	67	89	112	134	157	179	201	224	335
0.10	16	32	47	63	79	95	111	126	142	158	237
0.20	11	22	34	45	56	67	78	89	101	112	168
0.30	9	18	27	37	46	55	64	73	82	91	137
0.40	8	16	24	32	40	47	55	63	71	79	119
0.50	7	14	21	28	35	42	49	57	64	71	106
0.60	6	13	19	26	32	39	45	52	58	65	97
0.70	6	12	18	24	30	36	42	48	54	60	90
0.80	6	11	17	22	28	34	39	45	50	56	84
0.90	5	11	16	21	26	32	37	42	47	53	79
1.00	5	10	15	20	25	30	35	40	45	50	75
2.00	4	7	11	14	18	21	25	28	32	35	53
4.00	3	5	8	10	13	15	18	20	23	25	38
5.00	2	4	7	9	11	13	16	18	20	22	34
10.00	2	3	5	6	8	9	11	13	14	16	24
15.00	1	3	4	5	6	8	9	10	12	13	19

Note: Choose a basal area factor that gives a plot radius of between 15 and 20 metres (as highlighted).

Figure 17 Using an optical wedge prism to count tree basal area

a) b) c)

Notes: a) an 'in tree'—with overlap; b) an 'out tree'—space between tree and offset image of trunk; c) a borderline tree—slight overlap between tree and offset image of trunk
Source: http://en.wikipedia.org/wiki/Wedge_prism

Haglöf Factor Gauge

An alternative to an optical wedge prism is to use a Haglöf Factor Gauge to measure tree basal area. The Haglöf Factor Gauge typically has factors of 0.5, 1, 2 and 4. As for the optical wedge prism, trunks are measured at breast height (1.3 metres) and the appropriate basal area factor is chosen based on the plot radius for the average tree diameter at the site (Table 1).

The Haglöf Factor Gauge is used by placing the metal ring grip to the observer's forehead and stretching the chain to full extent. The observer then sights through the desired factor and counts the number of tree stems which are wider than the factor opening, turning in a complete circle.

A simple gauge can be made using a template calibrated to a gauge or prism of a known factor (figure 18). A gauge held at the fixed distance of 50 cm from the observer's forehead has a sighting ratio of 1:50. At this ratio, a 1 cm gap corresponds to 1 m^2/ha and a 0.5 cm gap corresponds to 0.25 m^2/ha. To determine the gap for a specific basal area factor (*BAF*) use the equation:

$$W = \sqrt{(BAF \times D^2/0.25)} \quad (5)$$

where W is the gap width in centimetres and D is the distance from eye to gauge in metres.

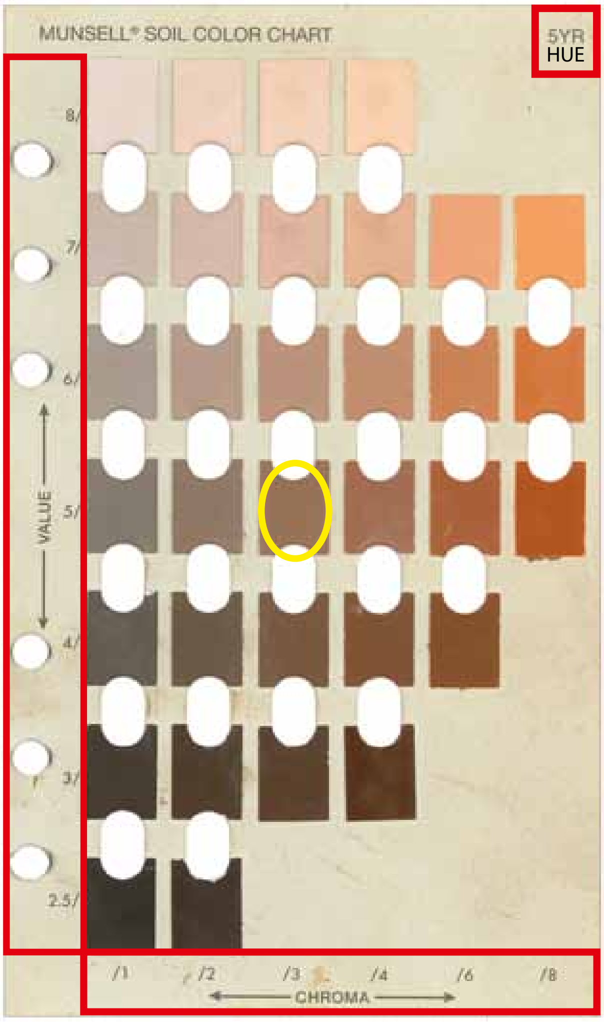
18 A gauge with four different basal area factors

Source: Northern Territory Department of Natural Resources, Environment, the Arts and Sport

Munsell Soil Color Charts

The Munsell Soil Color Charts are used to record soil, rock and lag colour. Three readings are taken: hue, value and chroma. The example circled in yellow in figure 19 has the readings of hue = 5YR, value = 5, chroma = 3 and is therefore recorded as 5YR5/3. To obtain the reading, a small amount of soil is held under the colour chart, to find the closest match. Both wet and dry recordings for soil crust (hard compacted surface soil) and disturbed (loose) soil are taken. A bottle is used to carry water to the site, to dampen the soil for the wet recordings.

19 Extract from the Munsell Soil Color Charts



Source: Munsell Color 1994, *Munsell Soil Color Charts*, revised edition, Macbeth Division of Kollmorgen Instruments Corporation, New Windsor, New York.

Digital camera

A digital camera recording 5 megapixels or more per shot is required to take site photos. This gives an image of at least 2580 wide × 2048 high pixels and a .jpg file size of 1.5 MB.

Vegetation identification books

Vegetation identification books are used to identify vegetation that is unknown to field operators.

Data entry

Data entry in the field can be done either electronically with a notebook or PDA into a spreadsheet template or in hard copy form. Where a hard copy form is used, the data must be entered into the digital spreadsheet template as a post-field processing step. Data entry is in two parts: (i) site descriptions and (ii) transect observations of vegetation cover observations at each metre along the transects. Appendix 3 has the complete site description and transects forms. Digital versions of these forms are available on the ACLUMP website, www.abares.gov.au/landuse/.

20 Data entry of observations along transects

	ground cover							woody vegetation <2m			woody vegetation >2m			
count	**crust**	**disturbed**	**rock**	**green leaf**	**dry leaf**	**litter**	**cryptogam**	**<2m green leaf**	**<2m dry leaf**	**<2m branch**	**in crown**	**>2m green leaf**	**>2m dry leaf**	**>2m branch**
1	1													
2		1												
3			1					1			1			
4			1						1		1	1		
5				1										1

Figure 20 shows an extract of the transect form. Observations are recorded as a '1'. Generally only one feature type is recorded for each observation category. For woody vegetation greater than 2 metres where the observation is within a live tree crown, 'in crown' is recorded as well as the canopy element intercepted—for example Count 3 for canopy gap or Count 4 when green leaf is intercepted. For dead trees, only the canopy elements of dry leaf or branch are recorded—for example Count 5.

Other equipment

Other useful equipment:

- flagging tape or star picket to mark the site for repeat visits
- bag or box to carry field equipment into site
- clipboard when using hard copy forms for recording data.

Appendix 3 Site description and transect forms

Site description form

Basic site description

Location description:____

Brief site description:____

Site ID (STATEnumber e.g. SA001): ____________________

Protocol: Ground cover monitoring

Revisit (Y/N):____________________

Field operators:____

Date (dd/mm/yyyy):____________________

Time (hh:mm):____________________

Zone (UTM/MGA94)(49-56):____________________

Geodetic datum (WGS84/GDA94):____________________

Easting:____________________

Northing:____________________

Landholder consent for data to be released (Y/N):__________

Slope (%):____________________

Aspect (degrees):____________________

Land use code (ALUMv7):____________________

Cropping (Y/N): ____________________

Commodity:____________________

Plant growth stage (establishment, immature/growing, mature, senescence/residue, none):

Management phase (abandoned, baled, burnt, cultivated, grazed, incorporated, mulched, sprayed, standing/none, other):

Photo numbers (7 natural/pasture sites; 5 cropping sites):____________________

Field spectra collected (Y/N): ____________________

Reflectance for field spectra:____________________

Vegetation description

Biomass estimate (kg/ha):________________________ Biomass method:________________________

Average non-woody vegetation height (m):____________

Fire occurrence (0 no evidence, 1 minor burn, <5% of site or >3 years, 2 recent /major burn >5% of site or <3 years):

____

Perennial vegetation (0-5%, 6-25%, 26-50%, 51-75%, 76-100%):____

Average woody vegetation height (m):________________

	Dominant species by biomass					
Vegetation structure	**Species 1**	**%**	**Species 2**	**%**	**Species 3**	**%**
Woody vegetation >2m						
Woody vegetation <2m						
Non-woody ground cover						

Tree basal area	Prism factor	Observer	Number of live trees	Number of dead trees	Converted (prism factor × No. live trees)
1. Centre					
2. North					
3. Northeast					
4. Southeast					
5. South					
6. Southwest					
7. Northwest					
				Total	

Average (live) tree basal area = total converted / 7: ________ m^2/ha

Land surface

Erosion

State of erosion (N none, A active, S stabilised, P partly stabilised):________________________________

Wind erosion (0 none, 1 minor, 2 moderate, 3 severe, 4 very severe):________________________________

Scald erosion (0 none, 1 minor <5% of site, 2 moderate 5–50% of site, 3 severe >50% of site):________________

Sheet erosion (0 none, 1 minor, 2 moderate, 3 severe):____

Rill erosion (0 none, 1 minor occasional, 2 moderate common, 3 severe corrugated):________________________

Gully erosion (channels >0.3 m deep) (0 none, 1 minor isolated, 2 moderate restricted to drainage lines, 3 severe branch away from primary drainage lines):____

Deposited materials

Deposited materials (sand <2 mm, gravel 2–60 mm, stones >60 mm):________________________________

Abundance (0 none, 1 very few <2%, 2 few 2–10%, 3 common 10–20%, 4 many 20–50%, 5 abundant 50–90%, 6 very abundant >90%):

____

Microrelief

Soil microrelief present in the site (0 smooth <3 mm variation, M mounds, D depressions, C crop rows):

____

Vertical interval between base and crest i.e. height (m):__________

Horizontal distance between crests (m):______________________

Biotic microrelief – specify up to 3 agents (NH horse, NS sheep, NC cow, NG goats, NP pigs, NM macropod, NL camel, NR rabbits), H human, B bird, T termite, A ant, V vegetation, O other):______________________

____

____

Soil description

Surface condition (when dry) – specify up to 3 conditions (G cracking, M self-mulching, L loose, S soft, F firm, H hard setting, C surface crust, X surface flake, Y cryptogam surface, T trampled, P poached, R recently cultivated, Z saline, O other):

____

____

Soil strength (0 loose, 1 very weak, 2 weak, 3 firm, 4 very firm, 5 strong, 6 very strong, 7 rigid):______________________

Surface cracks (except self-mulching soils or loose sand) (1 fine <5 mm, 2 medium 5–10 mm, 3 coarse 10–20 mm, 4 very coarse 20–50 mm, 5 extremely coarse >50 mm):______________________

Soil colour	Example	Crust dry	Disturbed dry	Crust moist	Disturbed moist
Soil hue	5YR				
Soil value	5				
Soil chroma	3				

Cryptogam

Cryptogam cover (none, <2%, 2–10%, 10–20%, 20–50%, 50–90%, >90%):______________________

Cryptogam colour: ______________________ Cryptogam wet/dry:______________________

Rock/lag

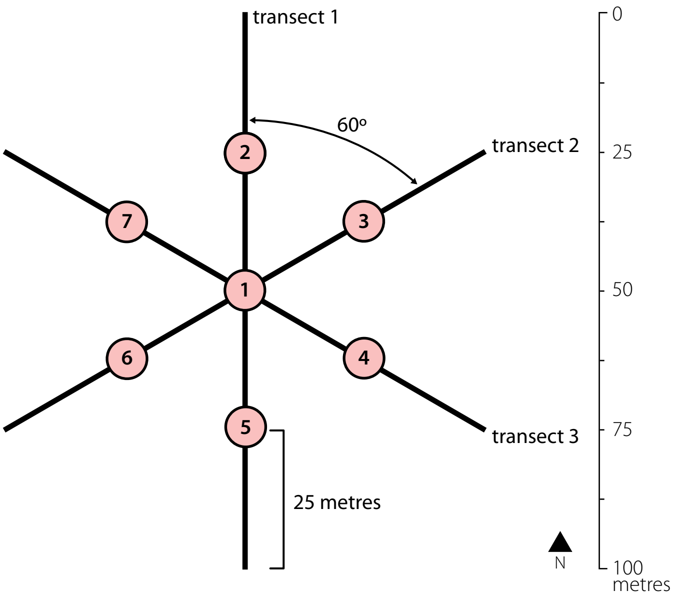
Rock/lag abundance (0 none, 1 very few <2%, 2 few 2–10%, 3 common 10–20%, 4 many 20–50%, 5 abundant 50–90%, 6 very abundant >90%):______________________

Average fragment size (1 fine gravelly 2–6 mm, 2 medium gravelly 6–20 mm, 3 coarse gravelly 20–60 mm, 4 cobbly 60–200 mm, 5 stony 200–600 mm, 6 bouldery 600–2000 mm, 7 large boulders >2000 mm):______________________

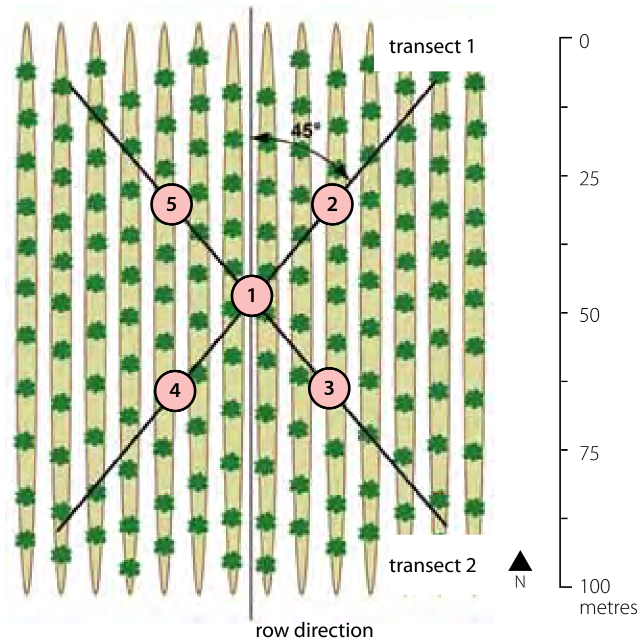
Rock/lag colour	1st dominant	2nd dominant	3rd dominant
Rock/lag hue			
Rock/lag value			
Rock/lag chroma			

Field transect layout

Natural environments or pasture sites



Cropping sites



The pink dots indicate the 7 positions to take tree basal area measurements in natural environments or pasture sites.

For all site photos stand at pink dot #1. Take photo of site centre looking down, then the remaining photos along the transect lines in the order numbered.

Transect 1 bearing: ____________________

Transect 2 bearing: ____________________

Transect 3 bearing: ____________________

Photo 1: ____________________

Photo 2: ____________________

Photo 3: ____________________

Photo 4: ____________________

Photo 5: ____________________

Photo 6: ____________________

Photo 7: ____________________

Transect 1 bearing: ____________________

Transect 2 bearing: ____________________

Photo 1: ____________________

Photo 2: ____________________

Photo 3: ____________________

Photo 4: ____________________

Photo 5: ____________________

Transect form

Site number: ____________ Sheet number: 1 Date:____________

	crust	disturbed	rock	green leaf	dry leaf	litter	cryptogam	<2m green leaf	<2m dry leaf	<2m branch	in crown	>2m green leaf	>2m dry leaf	>2m branch		crust	disturbed	rock	green leaf	dry leaf	litter	cryptogam	<2m green leaf	<2m dry leaf	<2m branch	in crown	>2m green leaf	>2m dry leaf	>2m branch
1															51														
2															52														
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49															99														
50															100														
SUB																													
TTL																													

Field measurement of fractional ground cover

Site number: ____________ Sheet number: 2 Date:____________

	crust	disturbed	rock	green leaf	dry leaf	litter	cryptogam	<2m green leaf	<2m dry leaf	<2m branch	in crown	>2m green leaf	>2m dry leaf	>2m branch		crust	disturbed	rock	green leaf	dry leaf	litter	cryptogam	<2m green leaf	<2m dry leaf	<2m branch	in crown	>2m green leaf	>2m dry leaf	>2m branch
1															51														
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TTL																													

Site number: ____________ Sheet number: 3 Date:____________

	crust	disturbed	rock	green leaf	dry leaf	litter	cryptogam	<2m green leaf	<2m dry leaf	<2m branch	in crown	>2m green leaf	>2m dry leaf	>2m branch		crust	disturbed	rock	green leaf	dry leaf	litter	cryptogam	<2m green leaf	<2m dry leaf	<2m branch	in crown	>2m green leaf	>2m dry leaf	>2m branch
1															51														
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50															100														
SUB																													
TTL																													

Appendix 4 Land use classification

1 Conservation and Natural Environments

1.1.0	**Nature conservation**
1.1.1	Strict nature reserves
1.1.2	Wilderness area
1.1.3	National park
1.1.4	Natural feature protection
1.1.5	Habitat/species management area
1.1.6	Protected landscape
1.1.7	Other conserved area
1.2.0	**Managed resource protection**
1.2.1	Biodiversity
1.2.2	Surface water supply
1.2.3	Groundwater
1.2.4	Landscape
1.2.5	Traditional indigenous uses
1.3.0	**Other minimal use**
1.3.1	Defence land - natural areas
1.3.2	Stock route
1.3.3	Residual native cover
1.3.4	Rehabilitation

minimum level of attribution

2 Production from Relatively Natural Environments

2.1.0	**Grazing native vegetation**
2.2.0	**Production forestry**
2.2.1	Wood production
2.2.2	Other forest production

3 Production from Dryland Agriculture and Plantations

3.1.0	**Plantation forestry**
3.1.1	Hardwood plantation
3.1.2	Softwood plantation
3.1.3	Other forest plantation
3.1.4	Environmental forest plantation
3.2.0	**Grazing modified pastures**
3.2.1	Native/exotic pasture mosaic
3.2.2	Woody fodder plants
3.2.3	Pasture legumes
3.2.4	Pasture legume/grass mixtures
3.2.5	Sown grasses
3.3.0	**Cropping**
3.3.1	Cereals
3.3.2	Beverage and spice crops
3.3.3	Hay and silage
3.3.4	Oil seeds
3.3.5	Sugar
3.3.6	Cotton
3.3.7	Alkaloid poppies
3.3.8	Pulses
3.4.0	**Perennial horticulture**
3.4.1	Tree fruits
3.4.2	Oleaginous fruits
3.4.3	Tree nuts
3.4.4	Vine fruits
3.4.5	Shrub nuts, fruits and berries
3.4.6	Perennial flowers and bulbs
3.4.7	Perennial vegetables and herbs
3.4.8	Citrus
3.4.9	Grapes
3.5.0	**Seasonal horticulture**
3.5.1	Seasonal fruits
3.5.2	Seasonal nuts
3.5.3	Seasonal flowers and bulbs
3.5.4	Seasonal vegetables and herbs
3.6.0	**Land in transition**
3.6.1	Degraded land
3.6.2	Abandoned land
3.6.3	Land under rehabilitation
3.6.4	No defined use
3.6.5	Abandoned perennial horticulture

4 Production from Irrigated Agriculture and Plantations

4.1.0	**Irrigated plantation forestry**
4.1.1	Irrigated hardwood plantation
4.1.2	Irrigated softwood plantation
4.1.3	Irrigated other forest plantation
4.1.4	Irrigated environmental forest plantation
4.2.0	**Grazing irrigated modified pastures**
4.2.1	Irrigated woody fodder plants
4.2.2	Irrigated pasture legumes
4.2.3	Irrigated legume/grass mixtures
4.2.4	Irrigated sown grasses
4.3.0	**Irrigated cropping**
4.3.1	Irrigated cereals
4.3.2	Irrigated beverage and spice crops
4.3.3	Irrigated hay and silage
4.3.4	Irrigated oil seeds
4.3.5	Irrigated sugar
4.3.6	Irrigated cotton
4.3.7	Irrigated alkaloid poppies
4.3.8	Irrigated pulses
4.3.9	Irrigated rice
4.4.0	**Irrigated perennial horticulture**
4.4.1	Irrigated tree fruits
4.4.2	Irrigated oleaginous fruits
4.4.3	Irrigated tree nuts
4.4.4	Irrigated vine fruits
4.4.5	Irrigated shrub nuts, fruits and berries
4.4.6	Irrigated perennial flowers and bulbs
4.4.7	Irrigated perennial vegetables and herbs
4.4.8	Irrigated citrus
4.4.9	Irrigated grapes
4.5.0	**Irrigated seasonal horticulture**
4.5.1	Irrigated seasonal fruits
4.5.2	Irrigated seasonal nuts
4.5.3	Irrigated seasonal flowers and bulbs
4.5.4	Irrigated seasonal vegetables and herbs
4.5.5	Irrigated turf farming
4.6.0	**Irrigated land in transition**
4.6.1	Degraded irrigated land
4.6.2	Abandoned irrigated land
4.6.3	Irrigated land under rehabilitation
4.6.4	No defined use (irrigation)
4.6.5	Abandoned irrigated perennial horticulture

5 Intensive Uses

5.1.0	**Intensive horticulture**
5.1.1	Shadehouses
5.1.2	Glasshouses
5.1.3	Glasshouses (hydroponic)
5.1.4	Abandoned intensive horticulture
5.2.0	**Intensive animal husbandry**
5.2.1	Dairy sheds and yards
5.2.2	Cattle feedlots
5.2.3	Sheep feedlots
5.2.4	Poultry farms
5.2.5	Piggeries
5.2.6	Aquaculture
5.2.7	Horse studs
5.2.8	Stockyards/saleyards
5.2.9	Abandoned intensive animal husbandry
5.3.0	**Manufacturing and industrial**
5.3.1	General purpose factory
5.3.2	Food processing factory
5.3.3	Major industrial complex
5.3.4	Bulk grain storage
5.3.5	Abattoirs
5.3.6	Oil refinery
5.3.7	Sawmill
5.3.8	Abandoned manufacturing and industrial
5.4.0	**Residential and farm infrastructure**
5.4.1	Urban residential
5.4.2	Rural residential with agriculture
5.4.3	Rural residential without agriculture
5.4.4	Remote communities
5.4.5	Farm buildings/infrastructure
5.5.0	**Services**
5.5.1	Commercial services
5.5.2	Public services
5.5.3	Recreation and culture
5.5.4	Defence facilities - urban
5.5.5	Research facilities
5.6.0	**Utilities**
5.6.1	Fuel powered electricity generation
5.6.2	Hydro electricity generation
5.6.3	Wind farm electricity generation
5.6.4	Electricity substations and transmission
5.6.5	Gas treatment, storage and transmission
5.6.6	Water extraction and transmission
5.7.0	**Transport and communication**
5.7.1	Airports/aerodromes
5.7.2	Roads
5.7.3	Railways
5.7.4	Ports and water transport
5.7.5	Navigation and communication
5.8.0	**Mining**
5.8.1	Mines
5.8.2	Quarries
5.8.3	Tailings
5.8.4	Extractive industry not in use
5.9.0	**Waste treatment and disposal**
5.9.1	Effluent pond
5.9.2	Landfill
5.9.3	Solid garbage
5.9.4	Incinerators
5.9.5	Sewage/sewerage

6 Water

6.1.0	**Lake**
6.1.1	Lake - conservation
6.1.2	Lake - production
6.1.3	Lake - intensive use
6.1.4	Lake - saline
6.2.0	**Reservoir/dam**
6.2.1	Reservoir
6.2.2	Water storage - intensive use/farm dams
6.2.3	Evaporation basin
6.3.0	**River**
6.3.1	River - conservation
6.3.2	River - production
6.3.3	River - intensive use
6.4.0	**Channel/aqueduct**
6.4.1	Supply channel/aqueduct
6.4.2	Drainage channel/aqueduct
6.4.3	Stormwater
6.5.0	**Marsh/wetland**
6.5.1	Marsh/wetland - conservation
6.5.2	Marsh/wetland - production
6.5.3	Marsh/wetland - intensive use
6.5.4	Marsh/wetland - saline
6.6.0	**Estuary/coastal waters**
6.6.1	Estuary/coastal waters - conservation
6.6.2	Estuary/coastal waters - production
6.6.3	Estuary/coastal waters - intensive use

Source: ABARES 2011, *Guidelines for land use mapping in Australia: principles, procedures and definitions, a technical handbook supporting the Australian Collaborative Land Use and Management Program*, 4th edn, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra, available at adl.brs.gov.au/data/warehouse/pe_abares99001806/GuidelinesLandUseMappingLowRes2011.pdf.

Appendix 5 Biomass estimation photo guides

Alluvial pasture yields

4250 kg/ha

2550 kg/ha

1950 kg/ha

Alluvial pasture yields

1000 kg/ha

700 kg/ha

450 kg/ha

Source: Qld DPIF 2003, *Pasture photo standards*, CD-ROM, cat. no. 2770000003292, Queensland Department of Primary Industries and Fisheries, Queensland Government.

Appendix 6 Quantitative estimation of biomass

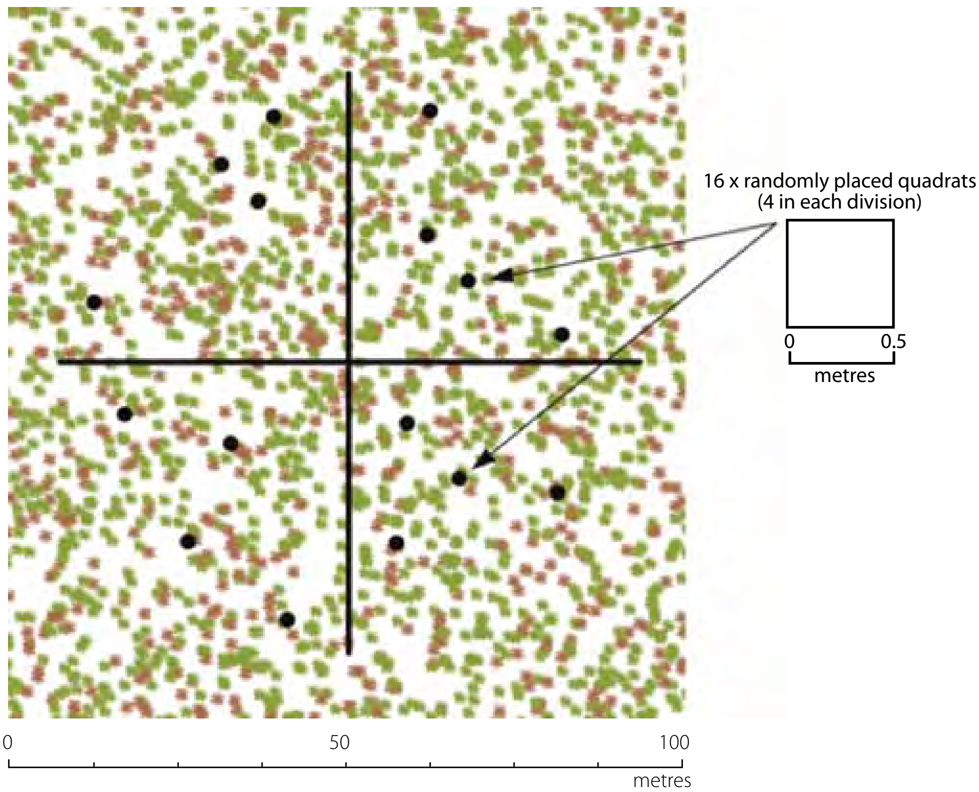
Biomass is visually estimated as part of the field assessment. However, a visual estimate of biomass can differ greatly between observers. Quantitative biomass measurements are preferable if time and budget allow.

The dry weight is generally reported taking into account species characteristics. All standing (attached) non-woody ground cover biomass is considered. This excludes litter.

The following scheme can be applied with the transect approaches described in the handbook at a scale of 1 hectare.

1. Realign the tapes to have one north–south transect and one east–west transect.
2. Cut the standing biomass within four quadrats (0.5 metres in length and width, or 0.25 square metres) randomly distributed, in each of the four sections differentiated by the tape.
3. Put all the biomass cut into one large bag, such as an industrial sized garbage bag.
4. Weigh the bag with *(A)* and without contents *(B)*—this represents the wet biomass for the quadrats. The quadrats are 4 × 0.25 square metres for each quarter of the site, representing a total of 4 square metres. Multiply the sum of biomass weight in kilograms for all 16 quadrats at the site *(A-B)* by 2500 to represent the wet biomass for 1 hectare.
5. Distribute the contents of the large bag on a tarpaulin and mix thoroughly.
6. Take a subsample to fill one small bag, such as a paper bag with dimensions of 0.3 × 0.3 metres.
7. Weigh the small bag of the subsample—with *(C)* and without contents *(D)*.
8. Seal the small bag and write on it: the weight of the large bag (used for wet biomass) *(B)*; the weight of the large bag and its contents *(A)*; the weight of the subsample bag *(D)*; and the weight of the subsample bag and the subsample biomass *(C)*.
9. Take the subsample to a laboratory to dry in an oven, generally at 60°C, until a constant weight is obtained *(E)*.
10. Calculate dry biomass (kg/ha) as the weight in kilograms of the dry biomass subsample *(E)* divided by the subsample proportion of total biomass, *(C-D)/(A-B)*, multiplied by 2500.

Quadrat sampling design for measuring biomass



Appendix 7 Cryptogamic crust

The data collected in the transects on cryptogam presence, refers to cryptogamic soil crust, also known as biological crust, microbiotic crust or biogenic crust. Cryptogamic crust is an assemblage of non-vascular plants—mosses, liverworts, algae, lichens, fungi, bacteria and cyanobacteria—which forms intimate associations with surface soils (Eldridge & Green 1994). Cryptogamic crusts are common in the arid and semi-arid rangelands of Australia.

The mixture of organisms forming the crust varies between areas based on climatic factors and soil types. The components and moisture of the crust determine its spectral reflectance. Variation in the reflectance of cryptogams can confound model relationships for predicting ground cover fractions from remotely sensed data. Thus the life state of cryptogam—whether wet or dry and colour—at a site is recorded. In most cases cryptogams will be dry and in a non-photosynthetic state. Dry cryptogams are brown or black and have a spectral reflectance similar to the underlying substrate (Karneili et al. 1999), and are therefore included in the bare soil cover fraction. Chlorophyll content of cryptogamic crusts increases rapidly after rainfall with moist cryptogams appearing green and exhibiting a spectral response similar to green vegetation (Karneili et al. 1999). Green cryptogam is assigned to the photosynthetic vegetation fraction. Cryptogams may also be observed in a state where reflectance is similar to the reflectance from the non-photosynthetic vegetation component, although of a lower magnitude.

Cryptogams should be considered on a site-by-site basis when calculating ground cover fractions (appendix 8). Where cryptogamic crust is thought to be contributing a significant proportion of the observed surface reflectance and model predictions from the remotely sensed data are not matching field recorded cover fractions, it is assigned to the 'best-fit' cover fraction based on reflectance.

Appendix 8 Calculating ground cover from field measurements

Field data results

Collection of field data using the prescribed method provides a table of point intersections in each of the three categories: ground cover (non-woody vegetation), woody vegetation less than 2 metres and woody vegetation greater than 2 metres. To determine the percentage cover in each category the point intersections for each component are summed for a site, to give a total count. A proportion for each component in a category is then calculated. Each proportion is derived by dividing the total count by the number of measurements taken at the site—300 for natural environments or pasture sites and 200 for cropping sites.

Calculating fractional cover

Field data can be applied to satellite imagery, such as Landsat or MODIS, to calibrate and validate models aimed at predicting ground cover components. Fractional cover, when applied to remote sensing, refers to the proportion of reflectance in an image pixel that comes from a specific component of the land cover. For example, the proportion of reflectance that is photosynthetic (green) vegetation. It is assumed that this proportion is the same as the proportion of the pixel occupied (that is, area) by the cover component. A common technique used in remote sensing for estimation of fractional cover is spectral unmixing.

The transect measurements acquired, according to the handbook, can be applied in a number of ways for cover estimation. For the 'Ground cover monitoring for Australia' project, the required fractions are photosynthetic and non-photosynthetic vegetative ground cover and bare soil (table 2). Cryptogams are generally added to the bare soil fraction, but may be added to the other categories depending on its characteristics (appendix 7). The features measured with the point intercept method may be assigned to different ground cover categories than that used for remote sensing model calibration. For example, when considered from the perspective of erosion mitigation, ground cover may include both organic (vegetation, cryptogam, litter) and non-organic features (rocks). The method in this handbook only considers allocation of individually measured components for measuring fractional cover for remote sensing model calibration and validation. Other uses should be considered with respect to the requirements and application for the data.

2 Allocation of ground cover components to fractional cover classes

Ground cover fraction	Ground cover components
Photosynthetic vegetation (PV)	green leaf
Non-photosynthetic vegetation (NPV)	dry leaf + litter
Bare soil (BS)	soil crust + disturbed soil + rock + cryptogam

To calculate woody vegetation cover less than 2 metres and woody vegetation cover greater than 2 metres the proportions for green leaf, dry leaf and branch are added together.

A worked example

For a site measured using the star-transect method 300 point observations are taken. To calculate the ground cover fractions the observations are summed for each component and divided by the 300 point observations. For the site in table 3 the ground cover fractions are 41 per cent photosynthetic vegetation (PV), 9 per cent non-photosynthetic vegetation (NPV) and 50 per cent bare soil (BS). The calculation of the woody vegetation components are also shown for completeness.

3 Fractional cover calculations from field transect measurements

	crust	disturbed	rock	green leaf	dry leaf	litter	cryptogam	<2m green leaf	<2m dry leaf	<2m branch	in crown	>2m green leaf	>2m dry leaf	>2m branch
Sum of transect intercepts	90	36	18	123	18	9	6	6	2	10	3	10	4	2
Proportion (sum/300)	0.30	0.12	0.06	0.41	0.06	0.03	0.02	0.02	0.01	0.03	0.01	0.03	0.01	0.01
Fractions														
PV				0.41				0.02				0.03		
NPV					0.09				0.04				0.02	
BS	0.50													

Note: BS = bare soil; NPV = non-photosynthetic vegetation; PV = photosynthetic vegetation.

From the perspective of a fractional cover remotely sensed product, all cover is seen from above, so the satellite 'sees' exposed cover only. Where woody vegetation occurs this will generally obscure ground cover and bare soil is likely to be underestimated. Hence sites for ground cover monitoring are located in areas dominated by non-woody vegetation and less than 20 per cent canopy cover.

Acronyms

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ACLUMP	Australian Collaborative Land Use and Management Program
ACRIS	Australian Collaborative Rangeland Information System
ALUM	Australian Land Use and Management (Classification)
BAF	basal area factor (of trees)
BS	bare soil
GDA94	Geocentric Datum of Australia (standard revised 1994)
GPS	Global Positioning System
JPG	file extension for Joint Photographic Experts Group photo images
LTBA	live tree basal area
MGA94	Map Grid of Australia (standard revised 1994) projection
MODIS	Moderate Resolution Imaging Spectroradiometer
NCST	National Committee on Soil and Terrain
NPV	non-photosynthetic vegetation
PDA	Personal Digital Assistant
PV	photosynthetic vegetation
PVC	polyvinyl chloride
RGB	red, green, blue (colour display bands for an image)
STBA	standing tree basal area
TBA	tree basal area
TERN	Terrestrial Ecosystem Research Network
WGS84	World Geodetic System (standard revised 1984) datum and spheroid
UTM	Universal Transverse Mercator projection

Glossary

Annual vegetation	Plants that complete their life cycle within one year from germination to fruiting and then dying (NSW RBG 2011).
Apedal	Peds are not apparent. Apedal soils are either single grained (incoherent) or massive (coherent) (NCST 2009 p. 171).
Vegetation in rows	Vegetation with a distinct linear component such as cropping rows.
Cryptogamic crust	An assemblage of non-vascular plants (mosses, liverworts, algae, lichens, fungi, bacteria and cyanobacteria) which forms intimate associations with surface soils (Eldridge & Green 1994); also known as biological crust, microbiotic crust or biogenic crust. The life state of a cryptogamic crust determines its reflectance and which cover type it is assigned to in fractional cover derived from remote sensing, though the bare soil cover type is typical.
Foliage projective cover	The fractional area (projected vertically) covered by one or more layers of photosynthetic tissue above a given land area; also known as foliage cover fraction.
Fractional cover	The percentage or fraction of an area (usually a pixel for the purpose of remote sensing) covered by the specific cover types of green or photosynthetic vegetation, non-photosynthetic vegetation such as stubble, senescent herbage and leaf litter, and bare soil or rock. Areas that have been burnt resulting in ash or blackened soil are considered a bare soil cover type.
Gilgai	Surface microrelief of mounds and depressions associated with soils containing shrink–swell clays (NCST 2009 pp. 129–30).
Ground cover	Any non-woody plant cover, both photosynthetic and non-photosynthetic, near the soil surface including vegetative litter (Murphy & Lodge 2002). Using remote sensing, ground cover is derived from fractional cover by excluding woody vegetation. Stones in contact with the soil are not included in estimates of remotely sensed ground cover as they cannot be reliably distinguished from the underlying soil.
Homogeneous site	A site where the spatial distribution of cover and species composition is consistent over the defined area. The area contains little topographic variation. The reflective characteristics of the area are consistent in the imagery for which the field data will be used to calibrate or validate.
Hummocks	Surface microrelief that rises above a flat surface with rounded to near vertical sides and rounded to flat tops. In some cases considered to be formed by biological activity. Common in northern Australia on soils with impeded drainage and in areas of seasonal ponding or flooding (NCST 2009 pp. 130–33). Amorphous hummocks are confined to soils with sandy-textured surface layers and are the result of resorting of sand by wind, which accumulates around obstructions, often to depths of many centimetres or even metres. The soil in the hummock is unconsolidated consisting of layers of accumulated soil and/or organic matter; often associated with scalding (Tongway & Hindley 1995: pp. 29, 47–48).

Natural or pasture environments	Native pastures, improved pastures or any other natural environment without a linear component. Includes savannas, grasslands, shrublands and woodlands.
Non-woody vegetation	Vegetation with no woody component such as herbs, grasses and forbs.
Ped	The natural unit of soil structure, or aggregate, formed by the soil's tendency to fracture along planes of weakness (NCST 2009 p. 171).
Pedal	A general soil science term indicating that soil structure is present. Pedal soils have observable peds and are divided into weak, moderate or strong (NCST 2009 p. 172).
Perennial vegetation	Plants whose life span extends more than one growing season (NSW RBG 2011).
Rangelands	In Australia, encompasses tropical woodlands and savannas in the far north; vast treeless grassy plains (downs country) across the mid-north; hummock grasslands (spinifex), mulga woodlands and shrublands through the mid-latitudes; and saltbush and bluebush shrublands that fringe the agricultural areas and Great Australian Bight in the south. Seasonal rainfall changes from summer-dominant (monsoonal) in the north to winter-dominant in the south. Soils are characteristically infertile. Distinctly characterised by great climate variability and the dominating influence of short growing seasons (Bastin et al. 2008 p. xvii).
Remote sensing	The process of obtaining information on vegetation attributes from a distance. Remote sensing records the reflected surface electromagnetic radiation of the vegetation cover and bare soil.
Rills and gullies	Channels cut by flowing water. May be initiated by water flowing down sheep or cattle paths. Aligned approximately with the maximum local slope (Tongway & Hindley 1995 pp. 27, 44–46).
Scalding	Results in massive loss of A-horizon material in texture-contrast soils exposing the A2 or B horizon which are typically very hard when dry and have extremely low infiltration rates. Often occurs on flat landscapes (Tongway & Hindley 1995 pp. 27, 47–48).
Sheet erosion	Progressive removal of thin layers of soil across extensive areas, with few if any sharp discontinuities to demarcate them. At an advanced stage, many sheeted surfaces are covered by layers of gravel or stone (collectively called 'lag') left behind after erosion of finer material (Tongway & Hindley 1995 pp. 27, 49).
Woody vegetation	Vegetation with a woody component such as stems or a trunk. Includes shrubs, chenopods and trees.

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Further information

This handbook will be updated from time to time. The current version and further information about ground cover monitoring for Australia are available from:

Australian Collaborative Land Use and Management Program at www.abares.gov.au/landuse

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An ArcMap document (.mxd) to aid in site selection is available from ABARES.

Send field data on CD or DVD to ABARES for inclusion in the national database.

The national database, MODIS-derived vegetation fractional cover and related metrics for Australia are available through the National Computational Infrastructure (https://rs.nci.org.au/FcSiteData/, https://rs.nci.org.au/FcModisGuerschman/ and https://rs.nci.org.au/FcModisMetrics/)