A Standard Design for Collecting Vegetation Reference Spectra: Implementation and Implications for Data Sharing

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Spectral signatures represent complex physical and biophysical relationships. Consideration and documentation of potential variables affecting these signatures are essential in obtaining meaningful spectra. A lack of standardised procedures and metadata collection has limited the transfer of spectra from one application to another. Here we describe the design and implementation of a standard method for the collection of spectral data and associated metadata. A specific application for revegetation assessment and monitoring is described. The concept of collecting consistent and accurate spectral data while minimising the influence of potential extraneous variation is relevant to field spectrometry in all environments and is particularly important for ecological applications.

INTRODUCTION

Spectral reflectance signatures represent the relationships between electromagnetic radiation (EMR) and the physical and chemical properties of the object of interest. They are the fundamental means of data representation and analysis in all forms of passive (reflected sunlight) remote sensing. The relationship between spectral reflectance and the biological, chemical, physical and atomic structure of gases, water, vegetation and soils has been explored using remote sensing techniques in areas of atmospheric chemistry, plant physiology, geological sciences, soil sciences, and limnology and oceanography since the 1960s. Coupled with recent advances in remote sensing technology and expectations of future developments in satellite technology, has been the increasing need to measure field-based reflectance spectra. Modern reflectance spectrometers are increasingly capable of measuring spectra with high precision and accuracy and are portable and easy to use.

For ecological applications, the relationships between EMR, biophysical features, illumination geometry and viewing geometry are complex. The quality of spectral reflectance, radiance or irradiance measurements can also vary depending on the operator and the calibration of the instrument and standard panel, and the localised environmental conditions. Consideration and documentation of each of these components are essential in obtaining meaningful spectra in the field. There are no national or international standards on in situ
reflectance measurement or management of such data in terrestrial applications. However, there are extensive specifications for ocean colour remote sensing (Hooker and McClain, 2000). Bojinski et al. (2003) describe a spectral database designed for data sharing with the data model including metadata entries of viewing and illumination geometry, localised environmental conditions and target descriptions. Lack of consistent field methodologies, appropriate metadata collection associated with spectral data, consideration of spatial and temporal variation in spectral response and accurate calibration, are factors that have prevented the transfer of knowledge from one application to another and also limited the commercialisation of field and imaging spectroscopy applications. Given the similarity in principles of ground-based sampling for any terrestrial application, with an appropriate sampling and data management design, it is possible that ground-based spectra collected by an individual could potentially be quantitatively useful for other scientists’ requirements, particularly for remote sensing feasibility studies.

Critical issues for making in situ measurements have been reported (e.g. Nicodemus et al., 1977; Duggin and Philipson, 1982; Milton, 1987; Curtiss and Goetz, 2001; Milton et al., 1995; Jupp, 1997; Salisbury, 1998; Schaepman, 1998; Milton, 2001). Factors that affect spectral measurements and those issues to be considered when designing a spectral library database have been conceptualised (Pfitzner et al., 2005). The standards described here were developed to enable a consistent and repeatable method and minimise the influence of extraneous factors in spectral reflectance, radiance and irradiance measurements. The spectral data and metadata standards foster the documentation of potential variables, are suitable for storage and retrieval within a database, increase the post-processing accuracy for reference spectra and form a knowledge base of spectral information with the vision of data sharing.

The Supervising Scientist Division (SSD), part of the Australian Government Department of the Environment and Heritage, has designed and implemented standards for the collection and storage of its spectral data and metadata. The general need for field spectral data and the specific requirements of the SSD are outlined. Both a methodology and metadata protocol for collecting in situ reflectance spectra to develop a spectral database are detailed. An Analytical Spectral Devices (ASD) FieldSpecPro-FR instrument is used in this paper, and focuses on measurements made in the field environment. References are made to laboratory measurements for calibration. The principles are transferable to other applications and spectrometers. However, it should be noted the FieldSpec-FR has a single field-of-view (FOV), unlike instruments that allow coincident reflectance and target measurements to be collected.

GROUND-BASED SPECTRA - NEEDS AND ISSUES

Reflectance data are collected for the calibration and validation of satellite and airborne multispectral and hyperspectral data (atmospheric conditions measured with a cosine receptor or calibration targets), development of spectral libraries (surface water, vegetation, soil, minerals and rocks), goniometric measurements, to develop and test models describing the relationships between the directional spectral reflectance of surfaces and their biophysical attributes, for accuracy assessments of the spectrometer itself (calibration and validation), and, for feasibility and cost-benefit analyses prior to commissioning acquisitions of expensive remotely sensed data. The types of questions that may be addressed in a feasibility study include: are the components of a land cover type separable? What spectral, radiometric and spatial scales are required for separation? What is the best time of year for maximum separability of a land cover type? (Curtiss and Goetz, 2001).

Spectral libraries are available in the public domain (for example, Grove et al., 1992; Clark et al., 1993; Satterwhite and Henley, 1990). However, reference spectra from public domain spectral libraries are often not transferable to the localised environment as a result of the variety of factors affecting reflectance spectra. For example, the optical properties of mineral compositions are affected directly or indirectly by many factors (such as chemical constituents, scale, moisture content, organic matter content, associated induced interferences of some minerals such as Mn and Fe, roughness and texture of the material), and there are a multitude of factors
affecting vegetation spectra that make it difficult to adequately populate a spectral library (different chemical compounds present in the vegetation, within species variability, dependence on growing season and scale dependence including background reflectance). Given the challenges facing the spectral ecologist, it is not surprising that there are few standardised vegetation spectral references in the public domain. The phenological state, plant architecture, and density and homogeneity of plants have an important influence on their spectral characteristics. Micro and macro-scaled physical and chemical changes are continually occurring within plants. The physio-chemical changes that cause spectral changes include daily variations (e.g. water balance responses), short-term growth and seasonal changes.

Additionally complicating the transfer of ground-based spectra from one researcher to another are the variance in techniques used to collect spectral information and the localised environmental conditions. While spectral measurements may be useful for a given application, there is a need for data which can be compared from site to site, independent of atmospheric conditions (Robinson and Biehl, 1979). The field campaign must be calibrated (with introduced uncertainty) and validated (reproducible) for both the measurement equipment and technique used.

FIELD DESIGN AND METADATA RECORDING STANDARD ISSUES

The factors that affect standardised measurements can be summarised to include: environmental (e.g. wind speed and direction, cloud cover and type, temperature, humidity, aerosols), viewing geometry (field-of-view, height above target and ground, instantaneous-field-of-view), illumination geometry (time and sun altitude, azimuth and orientation, smoke and haze), properties of the target (physical and bidirectional distribution function), and calibration of the instrument and reference standard.


It is assumed that the reflectance properties of the reference surface are known, that the angular field of view is small and incident radiation is dominated by its directional component and that viewing and illumination geometry are identical for the target and reference. However, the numerous variables that influence reference spectra must be considered. The experimental design, including timing of data collection, spatial scale of measurement, viewing and illumination geometry, integration and spectrum averaging and calibration procedures must be standardised to minimise extraneous variability in spectral response.

SSD’S SPECTRAL PROJECT

The main role of the SSD is to ensure protection of people and the environment from the effects of uranium mining and to encourage best practice in wetland conservation and management in an area known as the Alligator Rivers Region (ARR) located in northern Australia (Figure 1). The ARR is centred about 220 km east of Darwin in the Northern Territory covering an area of about 28 000 sq km. The ARR includes all of Kakadu National Park and the western boundary of Arnhem Land. Well known uranium sites in the Region include the operational Ranger mine, the rehabilitated Nabarlek mine (in Arnhem Land), the lesser known abandoned mines of the upper South Alligator River valley (such as Coronation Hill), and the Jabiluka mineral lease.

Research is conducted into the application of remotely sensed data for mine site monitoring and rehabilitation assessment. An important component of any rehabilitation assessment is an analysis of revegetation success. For this purpose high resolution data are required because of the variability and short range variation in surface cover, typical of the disturbed environment. While very high spatial resolution satellite data have been used contextually to identify temporal changes in
vegetation cover, individual species identification has been limited with broad multispectral bands. One-off remote sensing feasibility studies utilising hyperspectral data, such as CASI, HyMap and DeBeers Hyperspectral Scanner, have not provided transferable information because results are sensor specific and spatially and temporally dependant. Many remote sensing applications will remain in the research realm since they lack a knowledge base that quantifies spectral signatures through time, including the variation that occurs within and between vegetative species in the localised environment.

Temporal measurements of ground-based spectra can provide a defined expectation for separability likeliness. Plant mixtures and vegetation-soil mixtures can be modelled. This information is useful not only to the mining environment, but also for weed management in the surrounding mine environment of Kakadu National Park, assessing introduced weedy pastures in nearby Arnhem Land, and any remote sensing feasibility study involving weed and native covers.

**Project Aims**

SSD aims to understand the spectral response of vegetation species which are important for mine site rehabilitation assessment, including introduced weeds and natives, in order to make recommendations on the most appropriate monitoring method. To achieve this, fortnightly measurements of key species are sampled to establish a time series of spectral reflectance measurements. The Top End (northern Australia) is suitable for high frequency spectral reflectance measurements, apart from a few weeks during the monsoon season. Variations in atmospheric conditions (e.g. sun angle, humidity and haze from bushfires) do have to be accurately measured and recorded with the spectral response. Framework shrub and tree species are also targeted, as are spectra of waste rock, soil and rock outcrop. To account for within species variability, spatio-temporal spectra are measured along environmental gradients incorporating different densities and environmental backgrounds. These transect measurements are made in the late wet season during maximum phenological difference.

The project aims relating to fortnightly measurements of vegetative ground cover are addressed by the following research questions: What are the fortnightly spectral responses of ground cover vegetative species? Can ground-cover vegetative species be distinguished using ground-based reflectance spectra, and if so, what spectral resolution is required? At what phenological stage is maximum separability detected and is there a phenological stage when species are confounding? What are the implications for hyperspectral imaging throughout the year?

To answer these research questions, the research design needs to ensure that the spectral response is not confounded by extraneous factors such as localised changes in atmospheric conditions. The hypothesis is that with a well designed approach to collecting field spectral measurements and metadata, extraneous factors can be accounted for, accurate post-processing of spectra can be performed and the first database of Top End spectra relevant to the mine environment can be developed.

**Project Overview**

Reflectance characteristics over the visible to shortwave infrared (350-2500 nm) of several weed and native ground covers are being sampled fortnightly from permanent plots around the greater Darwin region. A challenge in the project design phase was to locate sites with homogenous dense cover that were unlikely to be disturbed from threats such as fire, development...
or mowing. Replicate plots were established with support from Commonwealth and Northern Territory Government Departments and private industry.

Priority species were identified with stakeholders. Dense and homogenous stands of plants addressed include pasture species such as Para grass (*Urochloa mutica*), Guinea grass (*Urochloa maxima*), Pangola grass (*Digitaria eriantha*), Jarrah grass (*Digitaria milanjiana*), Tully grass (*Urochloa humidicola*), Joint Vetch (*Aeschynomene americana*) and Stylo species (*Stylosanthes* spp.). Introduced weeds include Snakeweeds (*Stachytarpheta* spp.), Hyptis (*Hyptis sauveolens*), Mission grasses (*Pennisetum* spp.), wild passionfruit (*Passiflora foetida*), Calopo (*Calopogonium mucunoide*), Gamba grass (*Andropogon gayanus*), Couch grass (*Cynodon dactylon*), Rhodes grass (*Chloris sp.*), Gambia Pea (*Crotalaria goreensis*), Sicklepod (*Senna obtusfolia*), and native grasses (*Heteropogon* spp., *Sorghum stipodeum*, * Panicum mindanense* and *Schizachyrium fragile*) are included. Suitable sites for additional species are continually being sourced to further investigate potentially confounding spectral responses as well as including other weeds of national significance that threaten rehabilitation success in the mine environment. Fortnightly measurements, correlated with meteorological data, measurement metadata and cover descriptions will provide insight into subtle phenological spectral changes between and within species. It is envisaged that over time, a knowledge base, suitable for data sharing, will be used to provide the basis for undertaking cost/benefit analyses of proposed remote sensing studies. With this knowledge base, it may become possible to schedule airborne overpasses at times of greatest expected separability (chance provides highest cost effectiveness) between the spectral reflectance of targets of interest.

**SSD’S METHOD**

SSDs spectral measurement standards have been developed to include: adequate spectrometer warm-up time, laboratory verification of the spectrometer and reference panel calibration; images of the target at nadir, scaled set-up, horizon photographs and hemispherical photographs; subject information (classification, condition, appearance, physical state); subject background (scene background information similar to subject data); measurement information (instrument mode, date, local time, data collector(s), fore optics, number of integrations, reference material, height of measurement from target and ground, viewing and illumination geometry); environmental conditions (general site description, specific site location, geophysical location, sun azimuth and altitude, ambient temperature, relative humidity, wind speed and direction, weather instrument and sky conditions); and, of course, reflectance spectra.

**Laboratory Measurements**

Key sources of error are the standards to calibrate spectrometer devices as well as the measuring instruments themselves (Schaepman, 1998). We have developed a standard laboratory set up (detailed in Pfitzner et al., 2006), similar to that recommended by ASD (2000), which is used to measure and record the performance of both the spectrometer device and the standard panels over time. Temperature induced fluctuations of the spectrometer and source lamps are always minimised by allowing a 90 minute warm-up time. The performance of the spectrometer itself is measured fortnightly in the laboratory using a Mercury Argon (Hg/Ar) source lamp to measure and cross-calibrate the monochromator emission values in the visible-near infrared (VNIR) region and well-defined absorption features from a Mylar panel for the short-wave infrared (SWIR) region. The emission and transmission spectra, saved by date, are used to compare and document the response over time.

Adequate calibration of the reference panel is necessary to assure valid reflectance-factor data (Jackson et al., 1987). The assumption that a calibrated panel (near Lambertian) provides a good approximation to the true bi-directional reflectance function of the subject can be assessed in the laboratory. Prior to each field trip, in the standard laboratory set up, white reference (WR) averages are saved and used to check the panel K-factor performance over time to ensure a reliable reflectance factor. Two Spectralon® panels are used and measured, one of these remaining in the controlled laboratory environment. The laboratory measurements indicate the condition of the panel, whereby a relatively flat, nearly perfect reflectance
should be shown. Any deviation from previous measurements may indicate deterioration in the condition of the standard panel that may not yet be apparent by visual inspection. The panel can be cleaned if contamination is realised.

Measurements in the Field Environment

Resources are economised by a modified field buggy, which houses the equipment required for spectral and metadata recording. The Spectrometer is housed in the seat of the buggy and secured into position. A modified platform shades the spectrometer and houses the controlling laptop and WR panel at a height of one metre from the ground surface. The WR panel is protected in a wooden box. The lid of the box is opened only when WR measurements are being made to minimise contamination of the surface. A GPS is connected to the laptop, recording the position if the laptop in the spectrum header file. A weather station is mounted to the platform. Data sheets and digital camera are housed in the mesh carry basket. A stabilising pole and measurement pole are clipped to the buggy during transport. This setup requires one person only to record all spectral and metadata (Figure 2).

Viewing Geometry in the Field

The FOV must be appropriate to integrate and represent the geometric features of the target. The measurement diameter (at the surface) is equal to the height of the spectrometer above the surface multiplied by the FOV of the solid angle that admits light. In situ target measurements are made positioned on the side of the target point opposite the sun, as suggested by Deering (1989). A bubble leveller, attached to a stabilising pole is utilised (Figure 2). A weight, creating a shadow at nadir, is attached to the pistol grip and the plumbline used to locate the centre point. Once the centre point is located, the weight is retracted so it does not interfere with the spectral response of the panel or target. Experience has shown the stabilising pole is required to reduce the variations in spectral measurements seen whenever wind is a limiting factor. Measurements are made at a sensor zenith angle of 0° (nadir) and an 8° FOV, so that angle of acceptance is less than 20° full angle (Baumgardner et al., 1985; Deering, 1989).

At nadir, the only significant geometric concerns are the instantaneous field of view (IFOV) and its relationship to the size and distribution of the target element and the orientation of the sun azimuth relative to any preferred orientations of the target (Deering, 1989). For in situ ground cover measurements, we use a consistent 2 m height above the ground surface, providing a 28 cm diameter FOV (Figure 2). Note that the FOV is actually slightly larger that 28 cm due to the point spread function of

Figure 2. A scaled set-up photograph (left) showing the field buggy and direction, position and FOV. IFOV is shown right for Para grass sample.
the optics, however, this is not a limiting factor given all plots are greater than 1m². All sampled species except *Andropogon gayanus* (Gamba grass) reach a maximum height of two metres. Gamba grass is sampled from a height of 3 m, providing an approximate 42 cm diameter IFOV. A scaled set-up photograph and FOV photograph (Figure 2) are recorded along with the spectral data. *In situ* WR readings are made with the same geometries, except that the height of measurement is made at 1.5 m (approximately 21 cm diameter IFOV). This height difference violates the BRF assumption, but any influence is minimised. The height difference is required because the IFOV of the target is greater than the standard panel (25.4 x 25.4 cm). The WR panel is housed in a wooden case on the buggy, 1m from ground level. The WR is positioned <45 degrees from the target. Despite the change in viewing geometry, this set-up allows almost simultaneous sampling of the WR panel and the target because the stabilising pole can be repositioned from the WR panel to the target in a matter of seconds.

**Standard Spectralon® Measurements in the Field**

In the laboratory and the field, the spectrometer is allowed to warm up for 90 minutes to account for internal thermal equilibrium. Field reference panels are used to standardise measurements of target radiant flux in order to derive BRF on the assumption that the flux reflected from the panel can be used as a surrogate of the incident global irradiance (Kimes and Kirshner, 1982 in Rollin et al 1995).

The spectrometer is optimised prior to every new target reading in order to adjust the sensitivity of the instrument detectors according to the specific illumination conditions at the time of measurement and to subtract any electrical current generated by thermal electrons (dark current). In the laboratory and in the field, a WR spectrum is taken for every new sample. In the field, a WR spectrum is also taken prior to target reflectance measurements and whenever irradiance conditions change to ensure that changing levels of down welling irradiance do not cause the detectors to saturate (Taylor, 2004). If there is a change in atmospheric conditions between optimisation and spectral measurement, optimisation, WR and target spectral readings are redone.

In addition to acquiring a reflectance factor, reference standard spectra in the field can be used to indicate and record instrument and atmospheric stability, systematic and random noise and stray light. Dark current systematic noise is sensitive to temperature. Figure 3a illustrates typical WR spectra obtained under the controlled laboratory set up. Figure 3b illustrates systematic noise showing dark-drift smile (Taylor, 2004) in the region of least quantum efficiency (ultra-violet and blue regions) and steps between the silicon and SWIR-1 detectors as a result of inadequate spectrometer warm-up time (< 30 minutes). Because we sample in sub-optimal conditions (fortnightly measurements include the wings of the tropical monsoon), WR spectra are important documentation to support measurements of humidity and cloud cover. Figure 3c shows an unstable atmosphere in the water absorption bands (1400 and 1900 nm) as well as significant random noise in the SWIR-1-SWIR-2 arrays due to inadequate warm-up time. An unstable atmosphere is indicated by a computed reflectance that varies over time and this is assessed *in situ* on screen. Once at least two screen refreshes show stable spectra, a WR is recorded. Absorption minima and maxima at the atmospheric water absorption regions (Figures 3d and 3e), combined with metadata on meteorological conditions are useful documentation on illumination conditions at the time of sample measurement.

**Solar radiances (W/m²/steradian/nm)** measurements are recorded to highlight stray light interferences. After optimisation and WR spectra acquisition, a solar irradiance (raw digital number) spectrum is measured and saved. Figure 3f illustrates zero reflectance at the atmospheric water bands and no positive bias around the UV and blue regions due to stray light. Stray light documentation is important because it may affect the accurate detection of features such as chlorophyll *a* and *b* (electron transitions at 430 nm and 460 nm, respectively), water (O-H bend at 1400 nm), lignin (C-H stretch at 1420 nm), starch (O-H stretch, C-O stretch at 1900 nm) and water, lignin, protein and nitrogen, starch and cellulose (O-H stretch and O-H deformation at 1940 nm) (Curran, 1989). After the solar
radiance measurement, another WR is saved and the stabilising pole repositioned for target measurements.

**Target Measurements in the Field**

Averaging measurements will increase precision and reduce random error (Milton et al., 1995). However, errors may arise from sequential measurements (Deering, 1989). Statistical representative numbers of sample sizes are between 30-40 measurements (Schaepman, 1998) with 10 the absolute minimum (ASD, 2002). The FieldSpec-FR has a scan time of 0.1 seconds, so the time difference to measure the reference compared to the target of interest is more a limiting factor than the number of integrations of reflectance measurement. Milton (1987) suggests that replication of each measurement and careful data screenings are safeguards against short-term irradiance fluctuations between the target and reference. The standard panel spectra are used as visual *in situ* checks. Once a stabilised reading is obtained, 10 internal averages are saved. A dark current/optimisation average (25 spectra) is made for each measurement. The target measurement is captured with five replicates giving a total of 50 (5 x 10 scans) averaged spectra. Averaged stationary spectra are followed by averaged *roaming* spectra within the plot. Soil and/or litter interspace are sampled and recorded if appropriate (i.e. heterogenous covers).

If atmospheric conditions change during the short time required for these measurements, a WR sample is recorded, followed by repeat target readings. A scaled set-up photograph and FOV photograph at 2m height are recorded along with the spectral data. An accurate record of geographic location, time and sun azimuth and altitude accompany spectral data, as the position relative to the target changes over temporal scales. Solar azimuth and altitude are calculated post-field at the Geoscience Australia Compute Sun and Moon elevation site (http://www.ga.gov.au/geodesy/astro/smpos.jsp).

**Natural Illumination and Atmospheric Conditions**

Between the highest position of the Sun and that of the Sun lying low in the horizon, irradiance varies, but the reflectance of a Lambertian surface is independent of the position of the Sun for the same viewing angle. Radiance reflected back to the spectrometer is defined directionally, whereas irradiance received by the surface is
hemispheric. The incident diffuse irradiance depends on the height of the Sun and relative direct and scattered irradiance proportions that typically vary throughout the day and with atmospheric conditions.

Direct solar illumination is assumed to be the dominant illumination component when sampling is undertaken at high solar angles under ideal atmospheric conditions (low cloud cover, humidity, smoke and haze). Atmospheric conditions for spectral sampling are quite predictable in the tropics, but rarely are optimal conditions realised. The highest solar angle occurs during the wet season (between October and April) when cloud cover and humidity are typically at their peak. In the dry season (May-September), combined with a lower solar angle, smoke and haze from bushfires are common. We account for variations in direct solar illumination by sampling around +/- 2 hours of the time of highest solar elevation, which increases accuracy (Milton et al., 1995). The time, position, azimuth and altitude accompany spectral data.

Illumination contributions from diffuse hemispherical sources are another potential variable in obtaining reference spectra because reflectance spectra measured under solar illumination are strongly modified by the absorbing molecules in the atmosphere (Goetz, 1992 in Schaepman, 1998), and accounting for solar geometry and atmospheric fluctuation can increase accuracy (Milton et al., 1995). The environmental factors affecting measurement accuracy (water vapour, atmospheric scattering, clouds and wind) and suggested approaches to reduce these effects on spectral measurements have been documented (Salisbury, 1998; Curtiss and Goetz, 2001). Qualitative measurements of temperature, relative humidity, wind speed and direction are documented (Kestral 4000 Pocket weather station). Qualitative descriptions of cloud cover and type, using the standards of the Bureau of Meteorology (http://www.bom.gov.au/info/clouds/) are made (ten main cloud types, sub-divided into 27 sub-types according to their height shape, colour and associated weather). Photographic recording of the sky conditions and the state of the ground target at the time of spectral measurements can be helpful in interpreting and determining the data quality (Deering, 1989). In addition to scaled setup and nadir photographs, photographs of the eastern and western sky, as well as the hemisphere are documented to support quantitative and qualitative measurements of the hemispherical component. When measuring spectra in even slightly varying or limiting conditions, optimisation (dark current and WR) is performed frequently, radiance mode is viewed to verify that signal saturation is not occurring (ASD, 2002) and a new reference is recorded for every target.

The texture of the target (diffuse or specular), shadow and surrounds, as well as the operator of the instrument may also contribute to the hemispherical component. The operator maintains as much distance as possible from the target (utilising a stabilising pole) and dresses in low reflective dark coloured clothing. Photographic records and descriptions of the target and surrounds are addressed in the next section.

Target and Wavelength Dependency
Numerous references discuss the relationship between physical/biophysical variables and EMR, including: the way in which minerals absorb photons and their associated wavelength dependency (for example, see Hunt and Salisbury, 1970; Hunt et al., 1971a and b; Rowan et al., 1977; Hunt and Ashley, 1979; Hunt, 1977 and 1979; Goetz and Rowan, 1981); the spectral reflectance of vegetation (Collins, 1978; Horler et al., 1983; Milton and Mouat, 1989; Boochs et al., 1990; Elvidge, 1990; King et al., 1995; Clark et al., 1995; Campbell, 1996; Dawson and Curran, 1998; Datt, 1999 and 2000); and, characteristics of soils (Baumgardner et al., 1985; Irons et al., 1989).

The nature of the target in the localised environment must be documented. We follow the Australian Government Standard (refer to Department of Environment and Heritage, Guidelines for Biological Survey data). Documentation for vegetation includes: species name (or labelled sample), homogeneity (monoculture or mixed community), single layer or multiple layer, type and distribution of ground cover, apparent phenology, vegetation health and growth stage, disturbances and pattern of distribution (between species or age classes). Where a correlation is being established other than the interaction of the target with EMR, other measurements will be required (Leaf Area Index or
cover, moisture, canopy height, chemical analysis of compounds, biomass, height and leaf angle distribution). For soil characterisation, colour, pH, moisture, sample and field description (roughness, texture, moisture) are required. For such variables, a description and photograph are the minimum requirement for metadata records. Where samples are taken for further analysis (e.g. X-Ray Diffraction, chlorophyll concentration), sample numbers are associated with the reflectance and metadata record.

The Interrelationship of Metadata and Spectra

Metadata relating to illumination and viewing geometry, Spectralon® standard panel and spectrometer calibration, the target and spectra themselves are interrelated (Figure 4) and essential for accurate processing of spectral averages. Metadata enables outliers due to erroneous factors to be identified and attributed. These outliers can be excluded to maximise a true reference spectra.

SSD are designing a spectral database including forms describing these metadata components (Figure 5). The field reflectance measurements, field metadata and laboratory reference spectral and metadata will be stored in a SSD Spectral Database and allow these data to be queried and correlated.

Apart from obtaining meaningful spectra at the time of in situ data collection, considering the optical, local environmental, scalar and physical variables, aids in temporal measurement analysis. Figure 6 illustrates a time series of ground cover reflectance spectra, accompanied by selected metadata, for Stylosanthes humilis. Soil interspace was also measured. While the standards described above were implemented for each observation period, the components of metadata over time are necessary for defining reference spectra. This example shows changes in: date, time, position, sun azimuth, sun altitude, temperature,
humidity, cloud cover and type, homogeneity, cover, phenology and localised conditions. The standard and averaged spectra also change. While the spectra show a similar overall shape and position of absorption features, the depth and width of adsorption features and the magnitude of reflectance change as the sample senesces over time. The intensity of water absorption features also change over time. Whether or not these changes are a result of biophysical changes of the target or are attributable to the illumination conditions can only be assessed by an increased length of sampling record. It is only with accurate spectral and metadata both averaged “reference” spectral and any significant temporal change in the spectral response can be identified.

**CONCLUSION**

A spectral data collection methodology will be designed for specific project criteria. Whether the methodology is designed for a one-off sample for...
correlation with airborne or satellite multispectral or hyperspectral image data, or temporal measurements, spectral data must be collected in a well-designed and consistent manner. Minimum metadata requirements for the SSD Spectral Database have been outlined and these always accompany the spectral information. Extreme caution should be placed on using reference spectra without such metadata. Common practice should be to collect and document metadata associated with the spectral response. Any spectral data sharing necessitates the supply of both spectral and metadata information.

The benefit of obtaining accurate data for validated post-processed data outweighs the small additional investment in time required for metadata collection. An appropriate spectral and metadata collection can reduce systematic bias and minimise variability by accounting for extraneous factors. It is then possible that such data are useful for other scientists’ requirements, particularly for remote sensing feasibility studies.

REFERENCES


