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K Pfitzner, P Martin & P Bayliss

July 2004

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Compact Airborne Spectrographic Imager (CASI) and ground-based spectrometer data of Nabarlek – an overview

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1 Introduction

Compact Airborne Spectrographic Imager (CASI) data at 1 m spatial resolution covering the visible near-infrared (VNIR) region of the spectrum were acquired over the Nabarlek area in July 2002. Analytical Spectrometer Device (ASD) ground-based reflectance data of a number of land cover features on the Nabarlek site were captured on the 6^{th} August 2002. The CASI data was acquired in order to assess the usefulness of such remotely sensed imagery for rehabilitation assessment and as ancillary data to a number of Nabarlek site projects. ASD reflectance measurements were recorded in order to spectrally characterise a number of land cover features, including selected vegetation spectra, and to determine the spectral separability of these land covers. ASD reflectance measurements were also recorded in order to aid in the atmospheric correction process of the airborne CASI data.

This study is part of a broader aim to develop cost-effective and accurate remote sensing methods to monitor and assess minesite rehabilitation. For revegetation assessment, it is the visible – infrared range of the spectrum that potentially allows the identification of vegetation. Depending on the resolution of data obtained, composition, structure (trees, shrubs and grasses) and, potentially, information on the health and vigour of vegetation is achievable in the optical range. A major limitation of all ground-based surveys is that only small samples are taken. High resolution remote sensing provides a total picture to compare rehabilitated minesites with the surrounding country.

Multispectral and hyperspectral airborne missions in the Top End are infrequent. This is a result of the expense of mobilisation and the relatively limited number of user groups when compared to missions in southern States. The mobilisation costs for this CASI airborne mission was shared by three consortiums. During September 2002, the HyMap airborne scanner was commissioned in the Top End and an opportunistic capture of the Nabarlek site was requested. HyMap covers the visible – shortwave infrared (hyperspectral bands) at 2.5 m spatial resolution. In September 2003 and May 2004, a Quickbird satellite capture of 70 km^2 covering the visible and near infrared region of the spectrum at less than 1 m spatial resolution was acquired. In addition a DeBeers Hyperspectral Mapper survey, with similar specification to HyMap was acquired in May 2004.

The purpose of this report is to:

- Describe the CASI data and provide an initial assessment of the data obtained;
- Describe the characteristics of the ASD spectrometer and outline its usefulness for remote sensing projects;
- Outline the ASD spectra obtained by describing the physical parameters of land cover features measured;

- Document the processing undertaken of the ASD spectra and highlight their spectral features; and,
- Make recommendations for further work.

Other reports will detail other remotely sensed data captured.

2 CASI – overview

2.1 Characteristics of CASI data – general

The basic characteristics of the CASI sensor described below are sourced from ITRES (Innovation Technology Research Excellence and Service) (http://www.itres.com/docs/casi2.html) and the Ball Advanced Imaging and Management Solutions Pty Ltd (Ball AIMS) contract (see SSD file SG2002/0200).

CASI is an airborne mounted imaging spectrometer that acquires visible and near infrared imagery with spectral range adjustable between 400 and 1000 nm. Dynamic range is at 12 bits. Full calibration of the system (down welling irradiance measurements for at-aircraft atmospheric corrections) provides data in spectral radiance values ($\mu W\ cm^{-2}\ sr^{-1}\ nm^{-1}$). The sensor has a high Signal to Noise Ratio **(**480:1 at peak).

Field of view across-track is 37.8°. Pixel resolutions can vary from sub-meter to 10 meters, depending on aircraft flying height. Integration of GPS and high precision altitude sensors provides ortho rectification capabilities with the use of a Digital Elevation Model (DEM).

2.2 Nabarlek CASI data

The CASI scanner was flown over the Nabarlek mine and surrounds on 7th July 2002, commissioned to (Ball AIMS). The survey was flown at a height of 750 m, capturing 1 m pixel resolution. Approximately 600 ha of data were flown in the overpasses. Figure 1 provides an outline of the survey coverage overlaid on a scanned and georectified 1:50 000 topographical map of the region. Three lines of data were flown, deliberately covering undisturbed mining areas to the NW and SE of the minesite to aid in revegetation assessment.

Nineteen bands covering the visible blue to the near-infrared region of the spectrum were utilised (refer to Table 1). Ball AIMS performed baseline data processing, including standard radiometric, navigation, geometric correction and image mosaic. *eriss* supplied a high resolution DEM of the site to aid the ortho rectification process. This processing resulted in a 3978 x 5739 line pixel mosaic of the 19 bands in PCI PIX format (see Figure 1 for the extent of the mosaic coverage).

Figure 2 shows the true colour bands 7 5 2 (RGB) CASI mosaic. The old evaporation ponds, stockpile runoff pond, ore stockpile, mine pit, waste rock dump, waste rock run-off pond, plant area, construction camp and staff accommodation area are included in the survey (Figure 2). The west arm of the Cooper Creek traverses the survey area to the south east of the mine. Kadjirrikamarnda Creek is to the north west of the mine.

Figure 3 is a false colour subset of the CASI data, with vector mining features, roads and streams overlaid on 1:50 000 topographical data to illustrate the ortho rectified product. Figure 4 is a subset of Figure 3, covering the old plant area, plant runoff pond and part of the evaporation ponds. Figure 4 shows that individual tree canopies can be differentiated at the 1 m pixel spatial level.

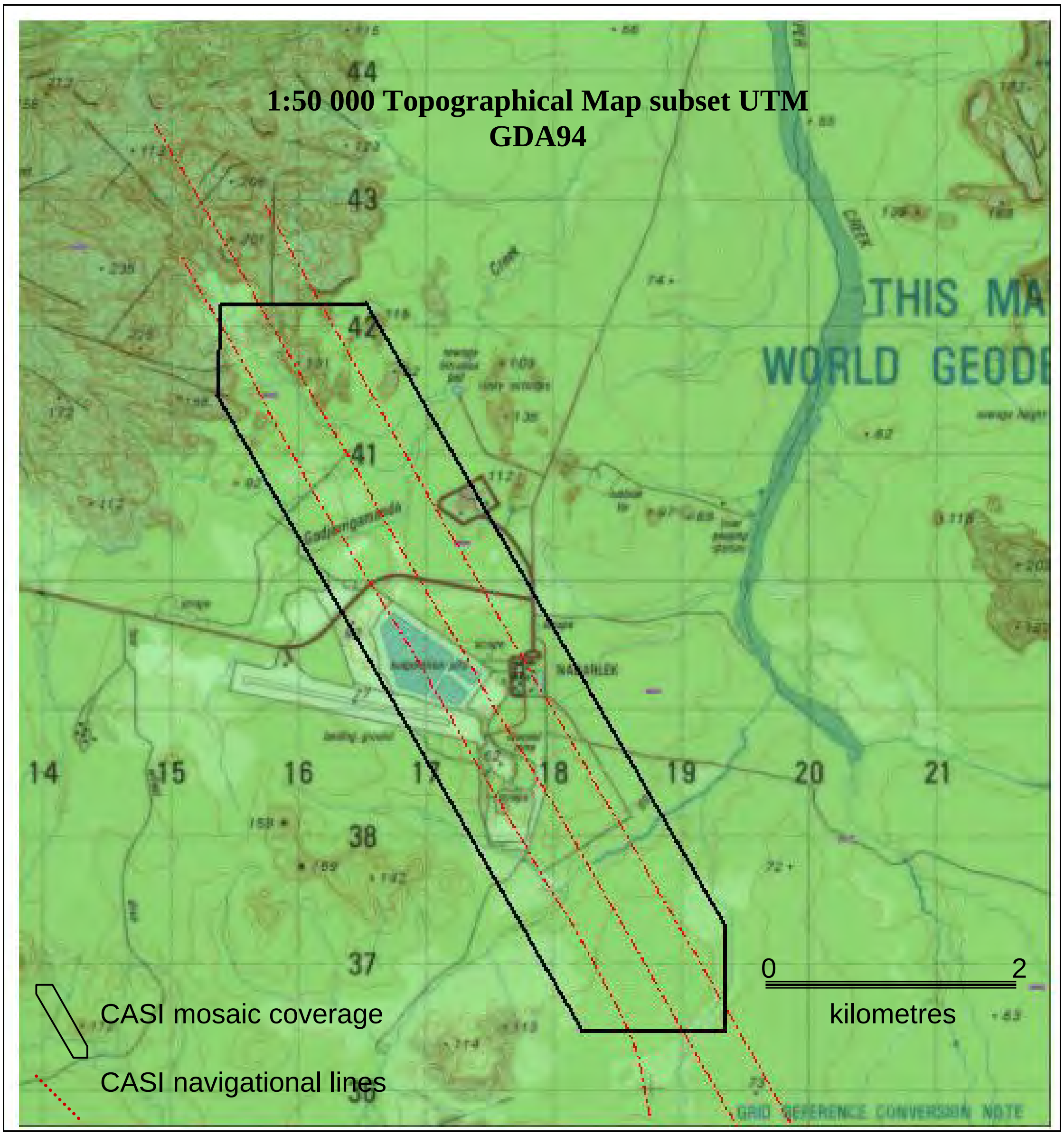


Figure 1 CASI coverage

Table 1 Spectral Characteristics of the CASI data

Band #	Wavelength (nm)	FWMH	Band #	Wavelength (nm)	FWMH
Band 1	419.000000	13.20	Band 11	710.500000	6.00
Band 2	443.899994	11.40	Band 12	733.400024	6.00
Band 3	490.200012	11.60	Band 13	748.799988	6.00
Band 4	529.400024	7.80	Band 14	780.400024	8.00
Band 5	549.099976	6.00	Band 15	800.599976	9.80
Band 6	578.299988	7.80	Band 16	850.500000	9.80
Band 7	646.599976	4.20	Band 17	900.500000	9.80
Band 8	671.299988	8.00	Band 18	950.400024	9.80
Band 9	678.900024	4.20	Band 19	957.099976	4.20
Band 10	693.299988	6.00			

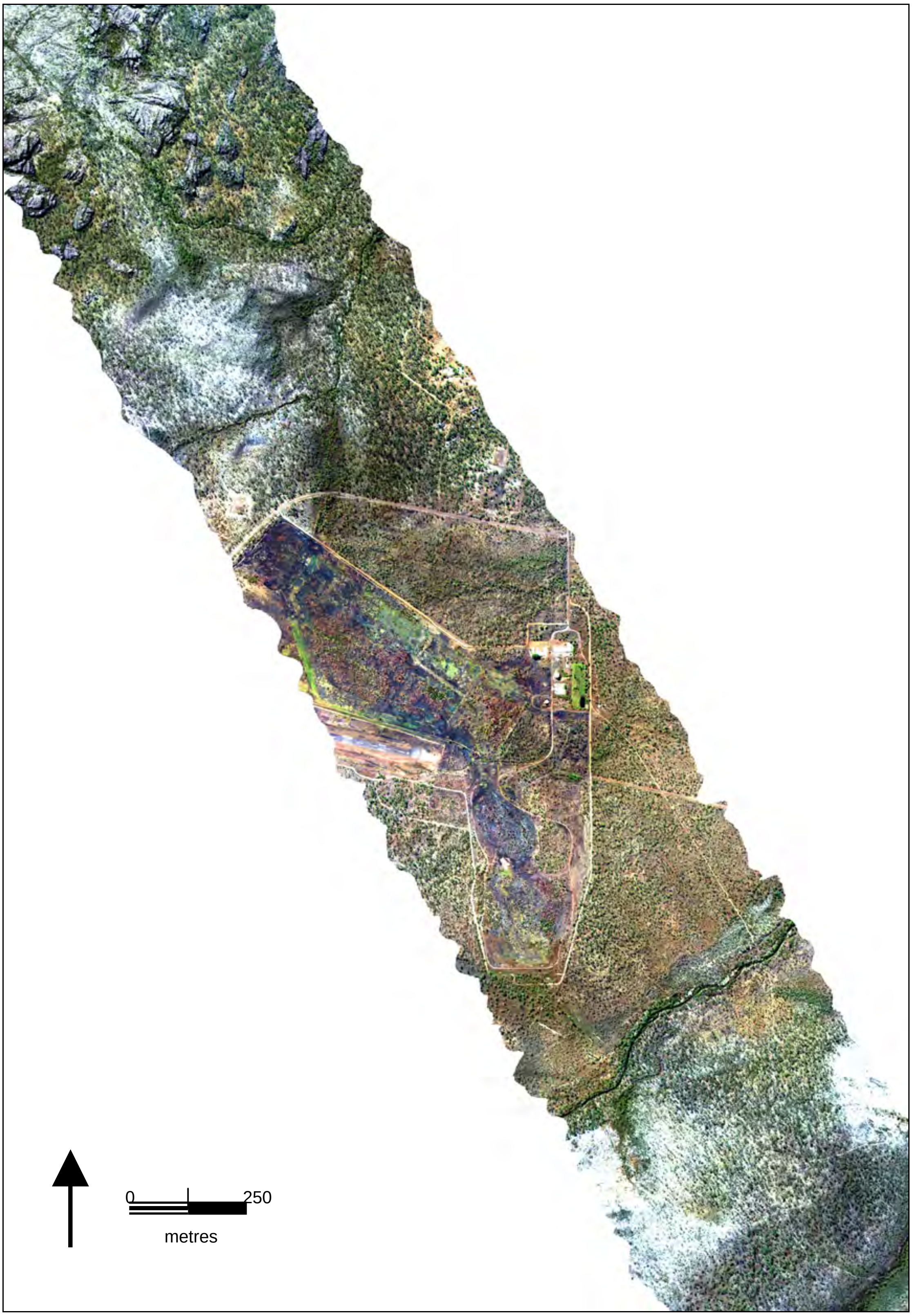


Figure 2 "True Colour" CASI data (bands 7 5 2 as RGB)

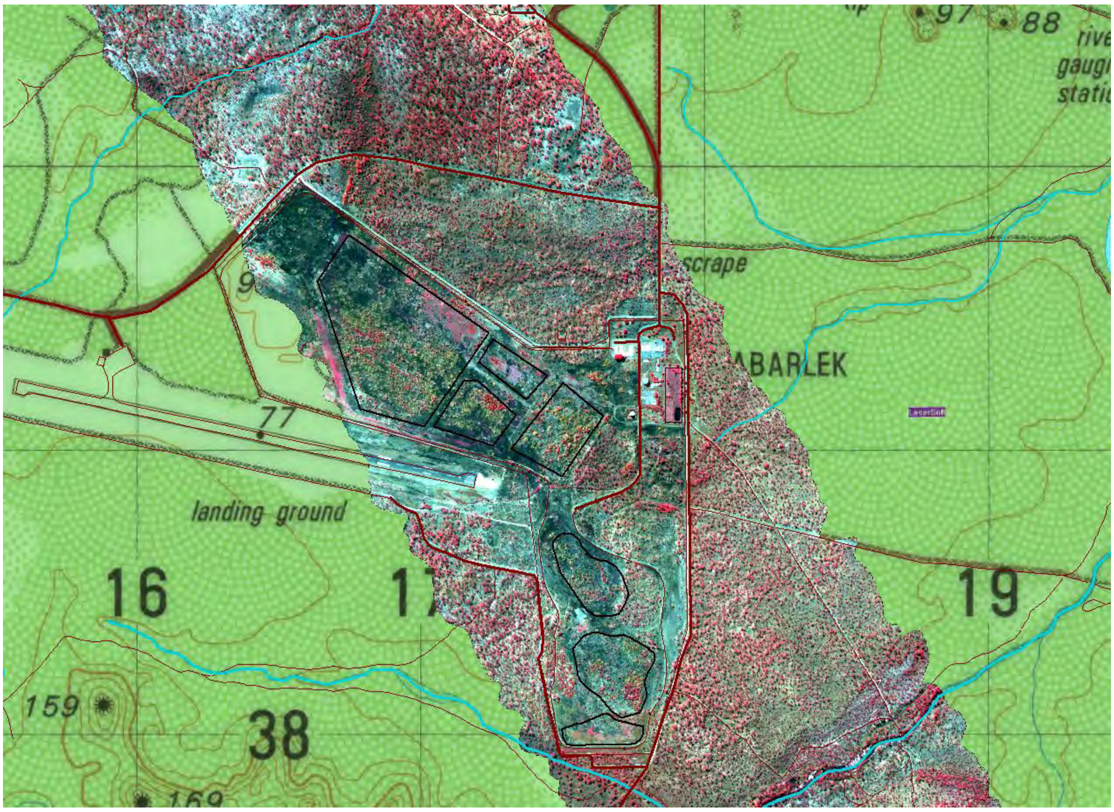


Figure 3 “False Colour” Subset of CASI data (bands 15, 8, 6 as RGB) with vector mining features, roads and streams overlaid on 1:50 000 topographical data. Green vegetation is displayed as red. Moist grasses are pink. A recent fire has impacted the minesite.

Figure 4 “False Colour” subset zoom of CASI data (bands 15, 8, 6 as RGB) covering the old plant area, plant runoff pond and part of the evaporation ponds

3 ASD – overview

3.1 Characteristics of the ASD Spectrometer

An Analytical Spectral Device (ASD) was hired from CSIRO (Land and Water Canberra). The spectral range of the spectrometer is 350 – 2500 nm. Three detectors are utilised: one from 350 – 1000 nm (VNIR) and two separate detectors in the shortwave infrared (SWIR) at 1000 – 2500 nm. Spectral resolution is of 3 nm at 700 nm and 10 nm at 1400 and 2100 nm. Sampling interval is 1.4 nm at 350-1050 nm and 2 nm at 1000-2500 nm. The joins are at 981 nm (between VNIR and SWIR1) and 1781 nm (SWIR1 and SWIR2). The spectrometer is capable of recording reflectance, radiance or irradiance.

3.2 Nabarlek ASD data

Spectral measurements were made in the field for the following purposes:

- To perform a feasibility study to understand if and how selected surface components of interest could be spectrally differentiated. Questions such as "is the material spectrally unique and what spectral resolution is required for detection?" were addressed.
- To make spectral identifications in the field for vegetation characterisation (such as relative chlorophyll content, moisture content, health, vigour, stress, senescence) that may be useful in indicating rehabilitation success.
- To make reflectance measurements of pseudo-invariant features (PIFs) for the empirical compensation of the atmosphere between the airborne sensor and the ground.
- To acquire reflectance measurements of surface features to enhance image analysis (by comparing endmembers of field signatures to remotely sensed data).

Spectra were collected on the 6th August 2002. The delay between remotely sensed data capture and field-based spectral measurements using the ASD was a result of site inaccessibility due to road closure for ceremony.

VNIR integration time was 34 seconds, with 25 samples per data value. Data was compared to a white reference, with 25 white reference measurements taken for each sample. A 5-degree field of view fore optic was attached.

Between 4 and 12 averages were gained for each of the 24 components spectrally measured. Plate 1 illustrates these features, which are labelled ASD1 – ASD 24.

ASD 1 “Mixed Paragrass (*Urocloa mutica)* and Hyptis weed herb (*Hyptis suaveolens)* ”

ASD 1 “Mixed Paragrass (*U. mutica)* and Hyptis weed herb (*H. suaveolens)* ”

ASD 2 Older Melaleuca leaves

ASD 2 Older Melaleuca leaves

ASD 3 Younger Melaleuca leaves

ASD 3 Younger Melaleuca leaves

Plate 1 Spectral measured land cover components

ASD 4 Ash covering iron gravel

ASD 4 Ash covering iron gravel

ASD 5 Mixed ash with Paragrass (*U. mutica*)

ASD 5 Mixed ash with Paragrass (*U. mutica*)

ASD 6 Paragrass (*U. mutica*)

ASD 6 Paragrass (*U. mutica*)

ASD 7 (green)

ASD 8 (drying)

ASD 7 and ASD 8 Paragrass (*U. mutica*)

ASD 9 Schist

ASD 9 Schist

ASD 10 White shade cloth (PIF)

ASD 11 Surrounds of white shade cloth

ASD 12 Concrete slab west (PIF)

ASD 12 Concrete slab west (PIF)

ASD 13 Concrete slab east (PIF). Light brown concrete of ASD 13 is in background. ASD 14 in foreground.

ASD 14 Concrete slab east (PIF). White painted concrete of ASD 14 is background. ASD 13 is in foreground.

ASD 15 Black shade cloth (PIF)

ASD 15 Black shade cloth (PIF)

ASD 16 Black speargrass (*Heteropogon contortus)*

ASD 17 American vetch (*Aeschynomene americana)*

ASD 17 American vetch (*A. americana)*

ASD 18 American vetch (*A. americana)*

ASD 19 Annual Mission grass (*Pennesetum pedicellatum*)

ASD 20 Senescing Couch grass (*Cynodon dactylon*)

ASD 21 Wild passionfruit vine (*Passiflora foetida)*

ASD 22 Sirato (*Macroptilium atropurpurem*)

ASD 23 Green Couch grass (*C. dactylon*)

ASD 24 Siver leaf wattle (*Acacia holosericea)*

The main aim of the spectral measurements was to ensure that PIFs were recorded for empirical atmospheric corrections between the airborne data and the ground. Another important aim was to spectrally characterise a range of vegetation types on the minesite, including weeds, to determine potential spectral separability at the time of CASI overpass. Due to time constraints, not all vegetation on the minesite was characterised.

PIFs were laid in the field prior to image capture and ground-based spectral measurements made. White and black 50% shade cloth were used as light and dark PIFs, respectively. In addition, spectral measurements were made of remnant concrete slabs. Four by four metre shade cloth were pegged and laid flat on bare areas of the study site. Using 50% shade cloth for calibrating CASI data was recommended by S. Phinn (2002 pers comm.). The 4 x 4 m area was chosen to ensure that a complete pixel would be identifiable in the CASI data. This allows for empirical adjustments of field spectra to the remotely acquired imagery in order to account for atmospheric effects and convert to reflectance. Reflectance measurements also aid in the atmospheric calibration verification process.

ASD 1 “mixed grasses along roadside” included Paragrass (*Urochloa mutica*), an introduced pasture grass, and the weedy herb *Hyptis suaveolens*. ASD 2 and 3 were reflectance measurements of Melaleuca leaves, with ASD 2 representing older leaves than the younger leaves of ASD 3.

ASD 4 recorded the reflectance of dark ash, ASD 5 of ash with some green grass, ASD 6 of green grass only, and ASD 7 of a long green grass leaf. ASD 8 measured an average of ASD 7 (rather than a closeup) of the long green grass. The grass in ASD 5-8 is Paragrass.

ASD 9 was recorded over schist boulders. The light pseudo invariant feature (PIF) was a 50% white shade cloth, recorded as ASD 10. ASD 11 recorded the background to the PIF (iron gravel and sediment with a patchy ash cover). ASD 12, 13 and 14 were recorded over large slabs of concrete. ASD 12 was measured over bluish tinge concrete, ASD 13 on light brown concrete and ASD 14 over bright white painted concrete. ASD 15 was recorded over the black PIF (50% black shade cloth).

ASD 16 recorded the reflectance of dry native Black speargrass (*Heteropogon contortus)*, ASD 17 of greenish-dry American vetch (*Aeschynomene americana*), a weedy shrub, and ASD 18 of drier *A. americana*. American vetch is an erect tall legume that grows in seasonally waterlogged soil and is classified as a wetland plant. ASD 19 was recorded over a patch of dry Annual Mission grass (*Pennisetum pedicellatum*). ASD 20 recorded the reflectance of Couch grass (*Cynodon dactylon*), a semi-aquatic introduced grass used for lawns and which appeared a yellowy-green colour at the time of sampling. ASD 21 recorded the weed wild Passionfruit vine (*Passiflora foetida*) and that for ASD 22, the reflectance of Sirato or purple bean (*Macropitilum atroppurpureum*). ASD 23 recorded the reflectance of green Couch (*C. dactylon*) and ASD 24 of small Siver leaf wattle leaves (*Acacia holosericea).*

4 Spectral processing of ASD spectra

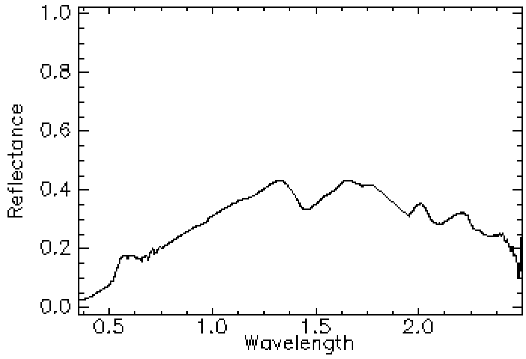
Each ascii file was opened, imported into Microsoft Excel and spectral averages of individual classes evaluated for spectral similarity. The total number of spectra for each endmember was then averaged. The 1.356 – 1.417 μm and 1.778 – 1.953 μm regions were excluded due to atmospheric water noise contribution. The averages (spectrally resampled to exclude noise contribution) were graphed.

4.1 Spectral Reflectance and Continuum Removed Results

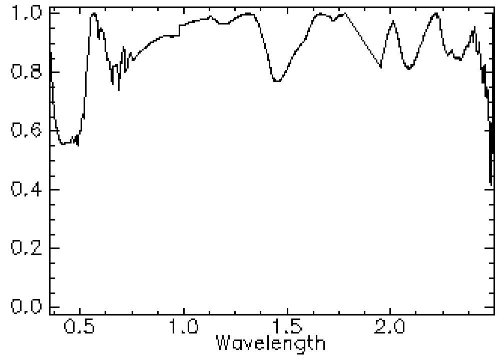
The spectral reflectance and continuum removed results are provided in Plate 2. Continuum Removal has been applied to normalise the reflectance spectra to allow comparison of individual absorption features from a common baseline. The continuum is a convex hull fit over the top of a spectrum utilising straight line segments that connect local spectra maxima. The aim of these graphs is to describe the magnitude of reflectance and to determine the position and depth of absorption features that may indicate the spectral separability of land cover components at the time of airborne acquisition.

Observation of the growth form of Passionfruit vine and Sirato at the time of CASI overpass indicated that these covers would not be identifiable from the airborne data. However, as these are known to colonise large areas rapidly, their spectra were recorded should they be required for future studies.

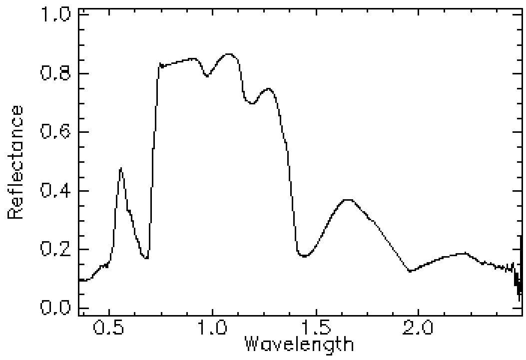
Plate 2 Reflectance and Continuum Removed ASD profiles



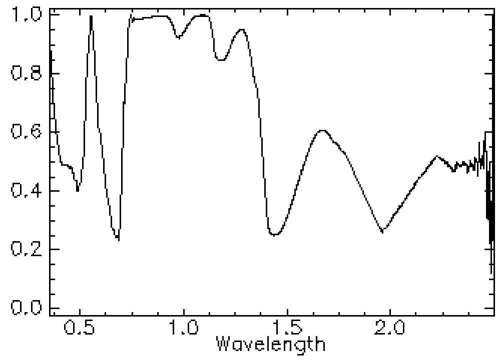
ASD 1 Reflectance



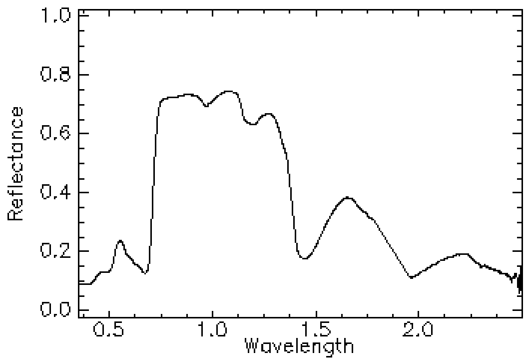
ASD 1 Continuum Removed



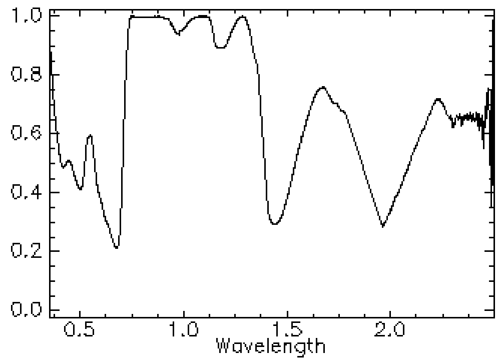
ASD 2 Reflectance



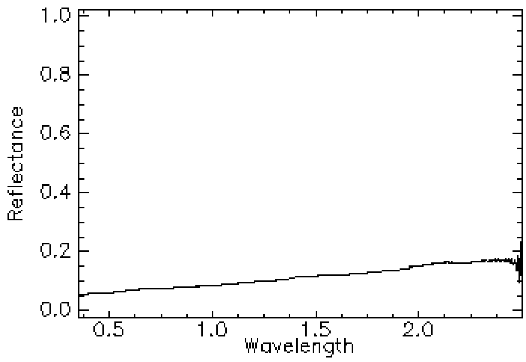
ASD 2 Continuum Removed



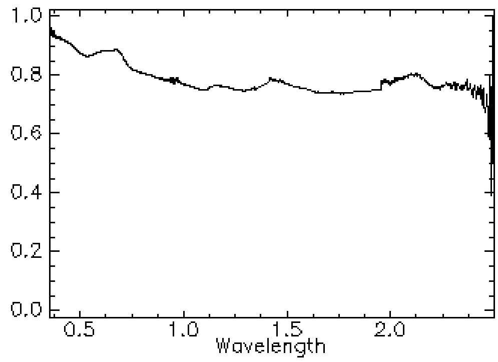
ASD 3 Reflectance



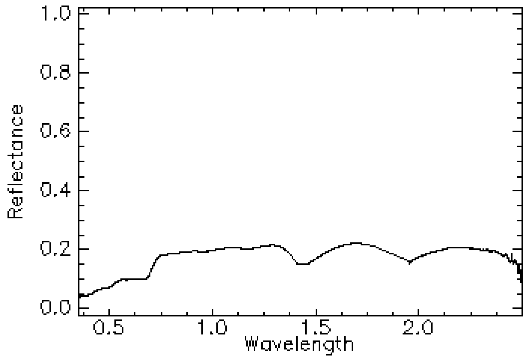
ASD 3 Continuum Removed



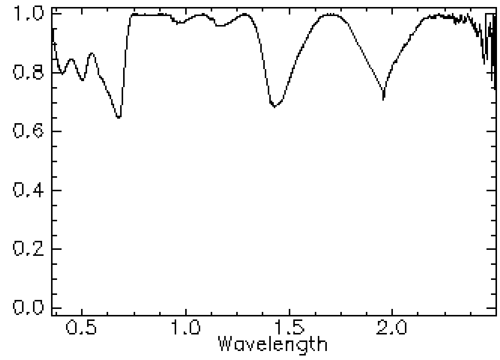
ASD 4 Reflectance



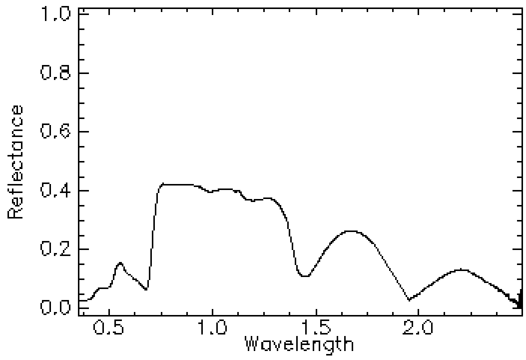
ASD 4 Continuum Removed



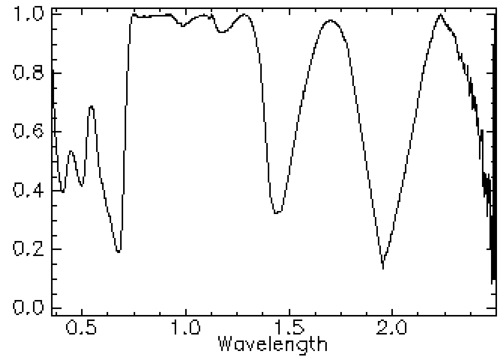
ASD 5 Reflectance



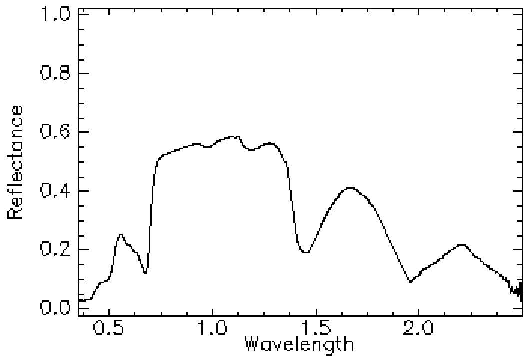
ASD 5 Continuum Removed



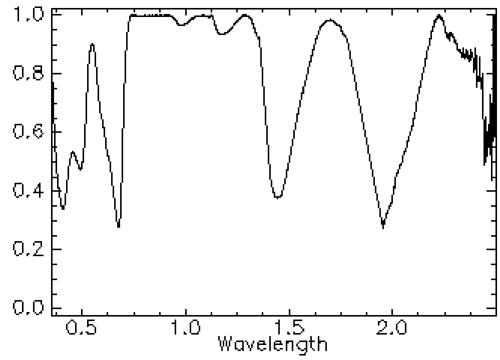
ASD 6 Reflectance



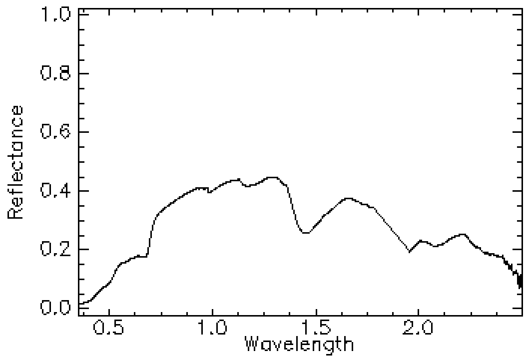
ASD 6 Continuum Removed



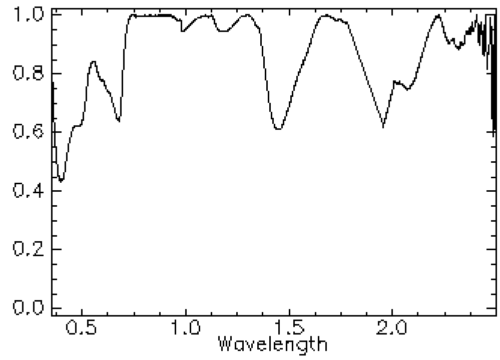
ASD 7 Reflectance



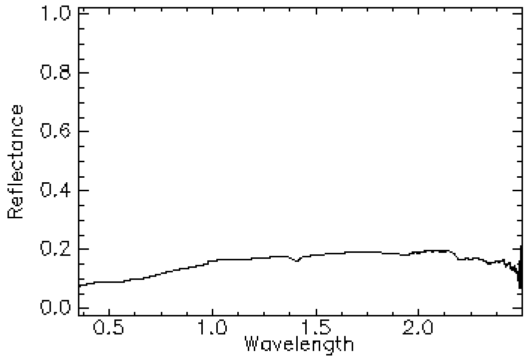
ASD 7 Continuum Removed



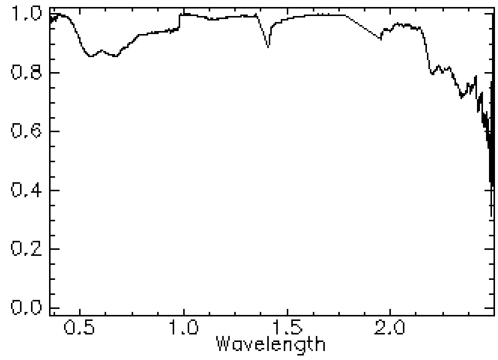
ASD 8 Reflectance



ASD 8 Continuum Removed



ASD 9 Reflectance



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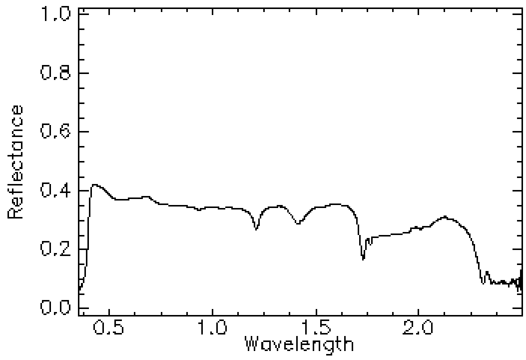
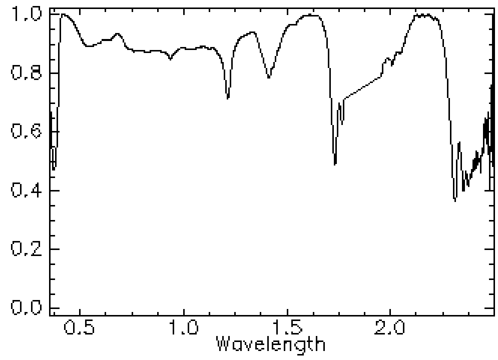
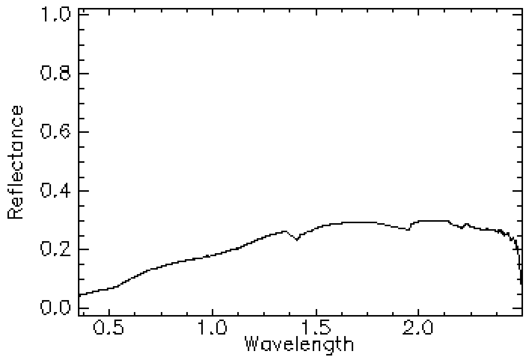


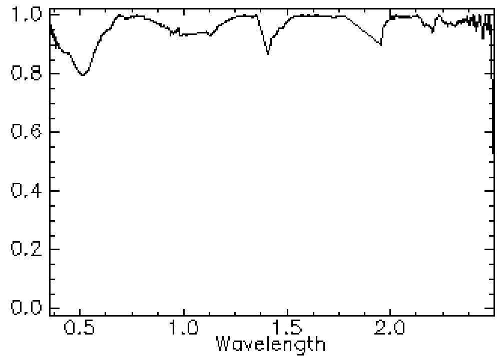
ASD 10 Reflectance



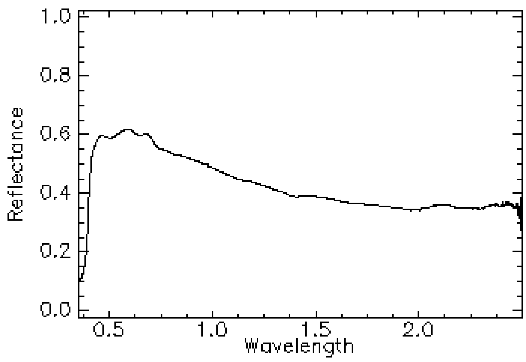
ASD 10 Continuum Removed



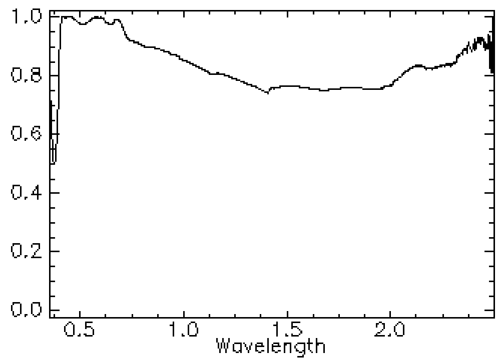
ASD 11 Reflectance



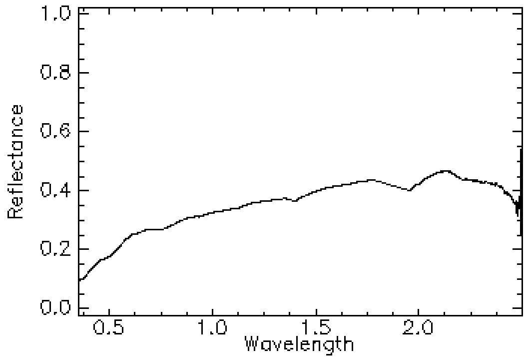
ASD 11 Continuum Removed



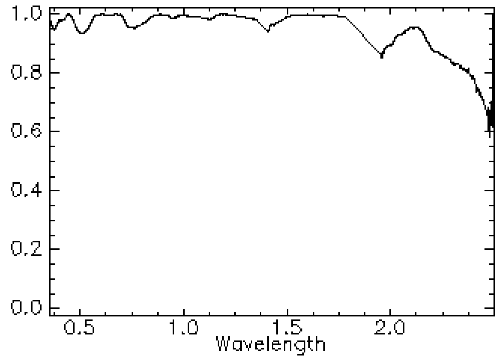
ASD 12 Reflectance



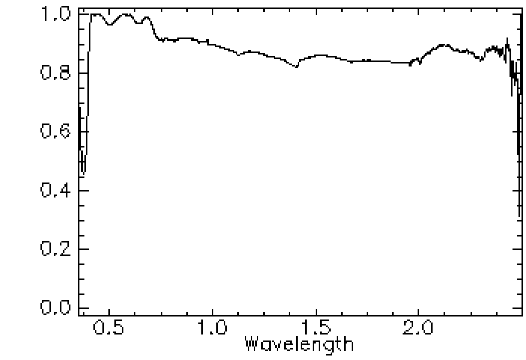
ASD 12 Continuum Removed



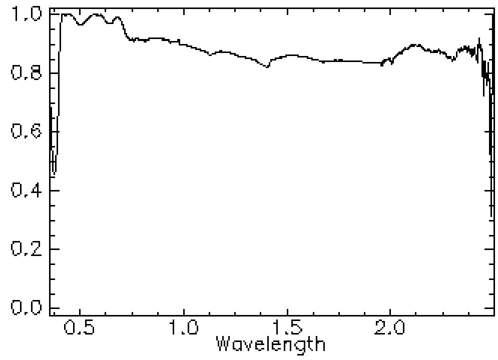
ASD 13 Reflectance



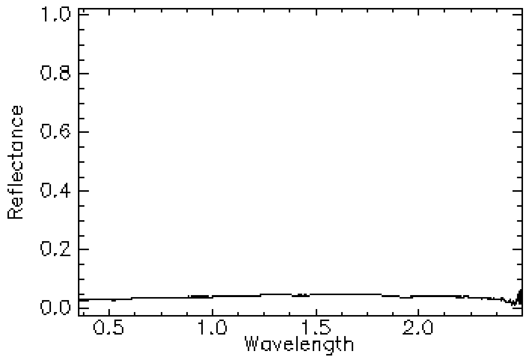
ASD 13 Continuum Removed



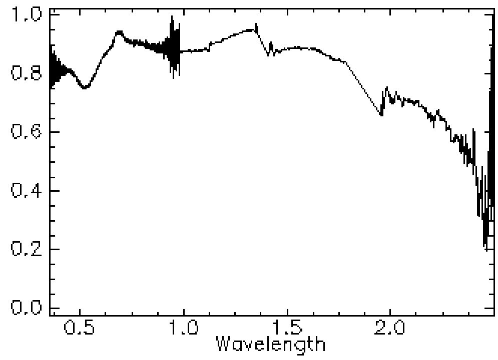
ASD 14 Reflectance



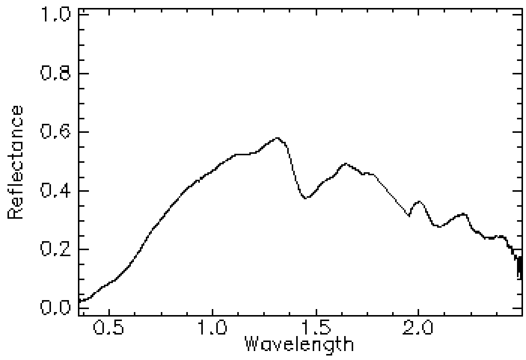
ASD 14 Continuum Removed



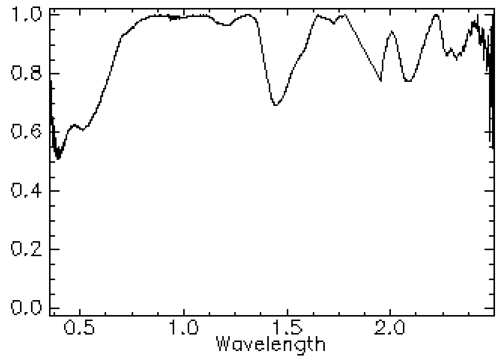
ASD 15 Reflectance



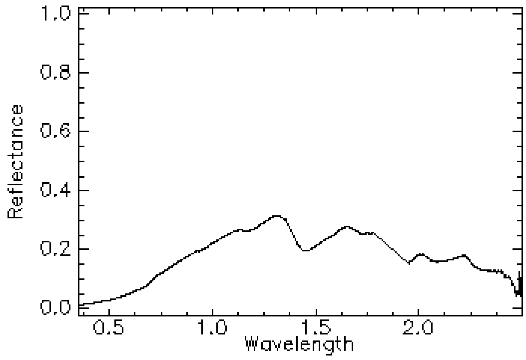
ASD 15 Continuum Removed



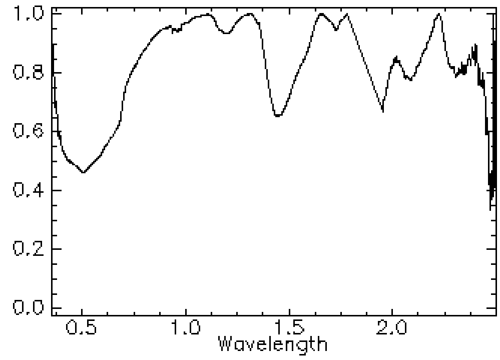
ASD 16 Reflectance



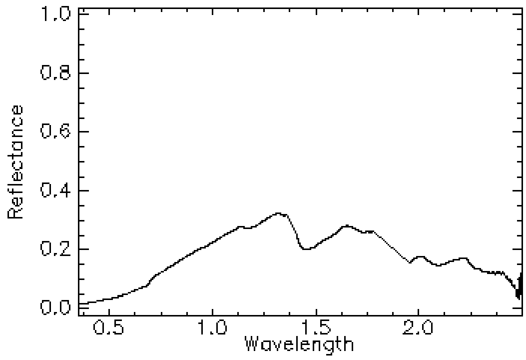
ASD 16 Continuum Removed



ASD 17 Reflectance



ASD 17 Continuum Removed



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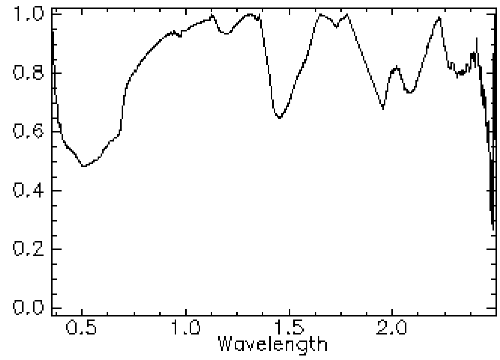
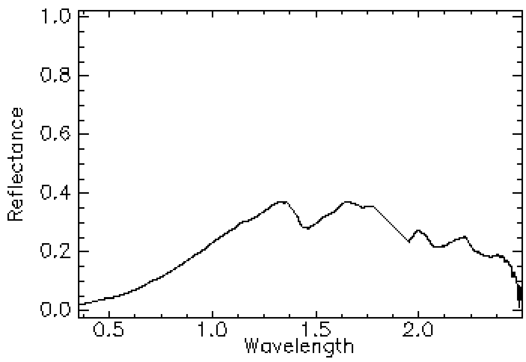
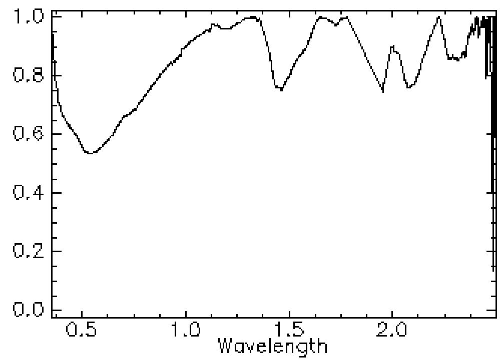


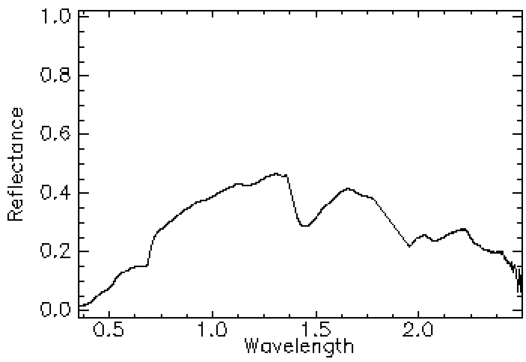
ASD 18 Continuum Removed



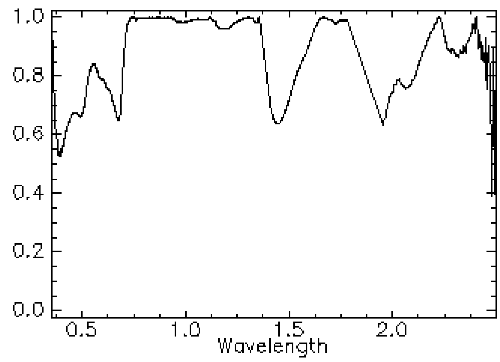
ASD 19 Reflectance



ASD 19 Continuum Removed



ASD 20 Reflectance



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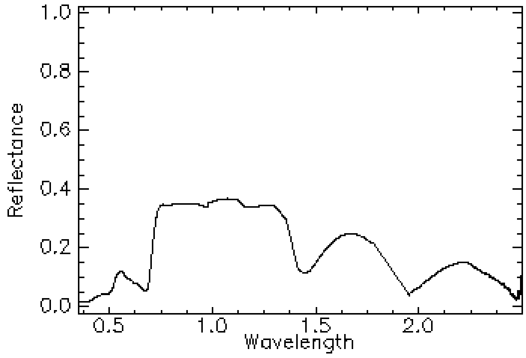
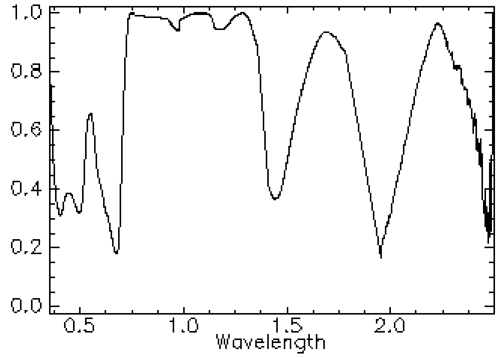
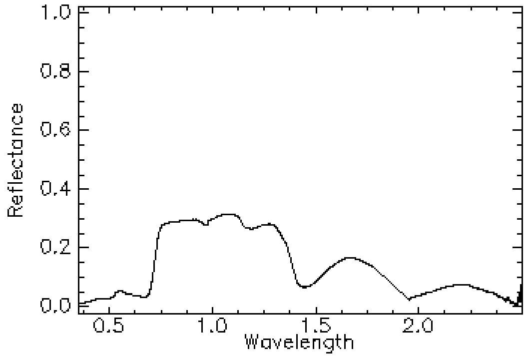


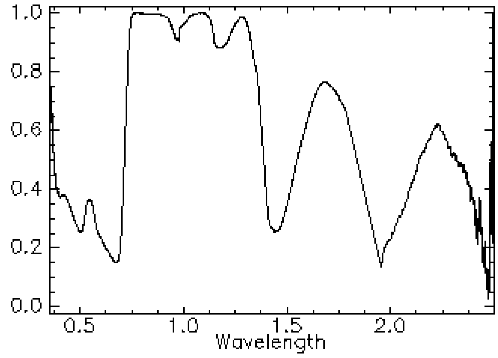
ASD 21 Reflectance



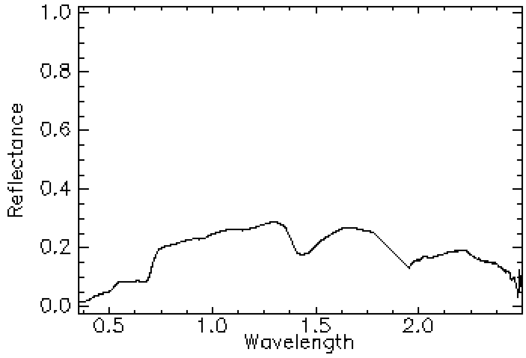
ASD 21 Continuum Removed



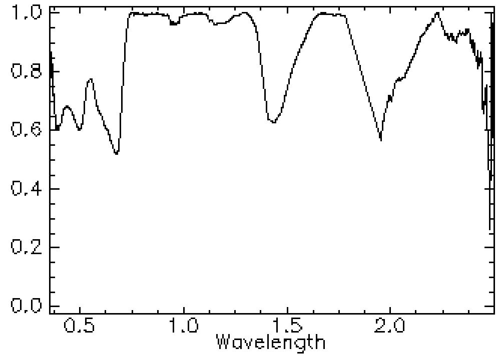
ASD 22 Reflectance



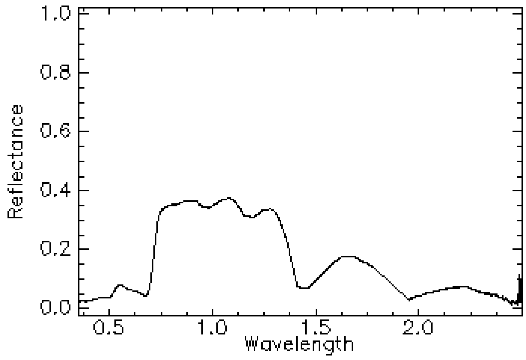
ASD 22 Continuum Removed



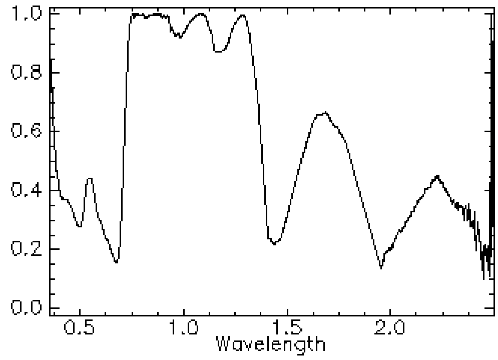
ASD 23 Reflectance



ASD 23 Continuum Removed



ASD 24 Reflectance



ASD 24 Continuum Removed

ASD reading 1 (mixture of the weeds Paragrass & Hyptis herb) displays an increase in reflectance to 0.56 μm with a minor chlorophyll *a* absorption around 0.68 μm. Reflectance increases in the near-infrared (NIR) to 1.3 μm. Water absorption features occur at 1.45 (broad) and 1.95 μm. The absorptions in the SWIR around 2.1 and 2.3 μm are likely due to lignin and cellulose absorption, typical of drying vegetation.

ASD readings 2 and 3 (Melaleuca leaves), 6 and 7 (green Paragrass), 21 (Passionfruit vine), 22 (Sirato) and 24 (Acacia leaves) show characteristic green vegetation curves. All have chlorophyll absorptions around 0.5 and 0.68 μm. The red edge increases to a maximum reflectance at ~ 0.74 μm for the ASD green vegetation readings. Slight 0.97 and 1.81 μm absorptions and stronger absorptions at 1.43 and 1.95 μm also occur. Although the general shape of the spectral curve is similar for all green vegetation, variations in the amplitudes and positioning of features occur.

The "blue" chlorophyll absorption is at slightly shorter wavelengths, 0.49 μm, rather than 0.5 μm, for ASD 2 (Melaleuca) and 7 (Paragrass). ASD 21 (Passionfruit vine), 22 (Sirato) and 24 (Acacia leaves) show stronger blue absorptions compared to the other green vegetation spectra. The chlorophyll absorption in the red region at 0.68 μm is strongest for ASD spectra 22, 24, 6 and 21. The red-edge shift is at shortest wavelengths for ASD 7 and at longest wavelengths for ASD 22. The 1.18 μm absorption is strongest for ASD 2 and less for 6, 7 and 21. The 1.44 μm absorption is strongest for ASD 24, 2 and 22 and lesser for 7 and 21. The 1.95 μm water absorption feature is strongest for 6, 21, 22 and 24. ASD 2 displays the greatest reflectance magnitude in the green and NIR, followed by ASD 3 and 7. ASD 22 displays the lowest magnitude red-edge shift that is at longer wavelengths.

ASD 4 (ash) shows a fairly flat featureless curve, increasing slightly in reflectance at longer wavelengths. An average signature of patches of green Paragrass with ash (ASD 5) show that the green vegetation characteristics of the grass are influencing the reflectance curve, as expected. Very slight chlorophyll absorptions in the blue and red (0.41 and 0.68 μm) are distinguishable in the reflectance curve, along with a very slight 0.9 μm water absorption. Water absorptions at 1.44 and 1.96 μm are also evident, particularly in the continuum removed (CR) curve. Despite slight vegetation absorptions, the overall vegetation curve is subdued due to the spectral mixing with ash. ASD 7 & 8 recorded the mixed reflectance of green and dry Paragrass, respectively. The mixed signature shows much less chlorophyll absorption in the blue and red regions, and a red-edge shifted to longer wavelengths compared to the green grass spectrum of ASD 7.

The schist spectra (ASD 9) is characterised by overall fairly low reflectance. Slight hydroxyl absorptions occur at 1.41 and 1.95 μm. Very minor absorptions (probably associated with iron) in the CR profile are observable at 0.55 and 0.68 μm.

ASD 10 (white shade cloth), 12 (bluish concrete), 13 (brownish concrete) 14 (whitish concrete) and 15 (black shade cloth) were measured as potential PIF targets for empirical line atmospheric calibration. Absorptions shorter than 0.43 μm are of no concern as this region is outside the atmospheric window. ASD 15 shows a fairly flat, featureless and low reflectance curve across the visible – near-infrared, indicating that the black shade cloth is a reasonable calibration target. The reflectance characteristics of the white shade cloth (ASD 10) do not make a good calibration target. Absorptions occur at 1.21, 1.41, 1.73, 1.77 μm. Iron absorptions occur at 0.54 μm and 0.8-0.9 μm (broad and shallow), which are probably due to the iron-rich gravel underneath the 50% shade cloth contributing to the reflectance. ASD 12 and 14 may provide alternative calibration targets of high reflectance, despite the minor absorption around 0.5 and 0.65 μm and a shallow absorption across the remaining spectrum.

ASD 11 (an iron-rich gravel with ash) reflectance curve shows an increase from the visible to 1.36 μm, with the CR curve showing absorptions at 0.51 and a broad absorption from 0.8 – 1.1 μm. ASD 11 is also characterised by hydroxyl and clay absorptions at 1.41, 1.96 and 2.20 μm.

ASD 16, 17, 18, and 19 are reflectance measurements of dried vegetation. The spectral profile shows an increase in reflectance to the NIR with 1.4, 1.9 and 2.0 μm absorptions, as well as a very slight 1.73 μm absorption. There are slight reflectance differences in the visible region. ASD 16 is characterised by a higher magnitude in reflectance and shows an increase at 0.47 μm and a very minor absorption centred at 0.50 μm. ASD 17 and 18 have broader shallow absorptions centred at 0.51 μm, whereas for ASD 19, the feature is at 0.54 μm.

ASD 20 of yellowing Couch grass shows a loss of chlorophyll absorption compared to the green vegetation, but maintains distinct absorptions in the reflectance curve at 0.49 and 0.68 μm.

4.2 ASD resampled to HyMap and CASI spectral ranges

The discussion above highlighted similarities in the reflectance of some land cover features. ASD 16, 17, 18 and 19 represent dried vegetation. ASD readings 2 (older Melaleuca *leaves*), 3 (younger Melaleuca leaves), 6 (Paragrass leaf), 7 (tall Paragrass clump), 21 (Passionfruit vine), 22 (Sirato) and 24 (Acacia leaves) represent green vegetation.

ASD readings 1 (mixed Paragrass and Hyptis herb), 5 (Paragrass mixed with ash), 8 (tall drying Paragrass clump), 20 (Couch grass) and 23 (Couch grass) represent less green vegetation. The remaining spectra 4 (ash), 9 (schist) and 10-15 (PIFs) are discussed separately. The spectral groups were resampled to the HyMap spectral range (Plate 3) and CASI spectra range (Plate 4) to identify the potential spectral separability of these cover types. Note that an airborne HyMap data collection occurred in September 2002. Comparisons within and between these vegetation groups were made to assess whether the field spectra were potentially spectrally separable, both between vegetation groups and for species within groups.

Plate 3 ASD spectra resampled to HyMap band range, reflectance and continuum removed

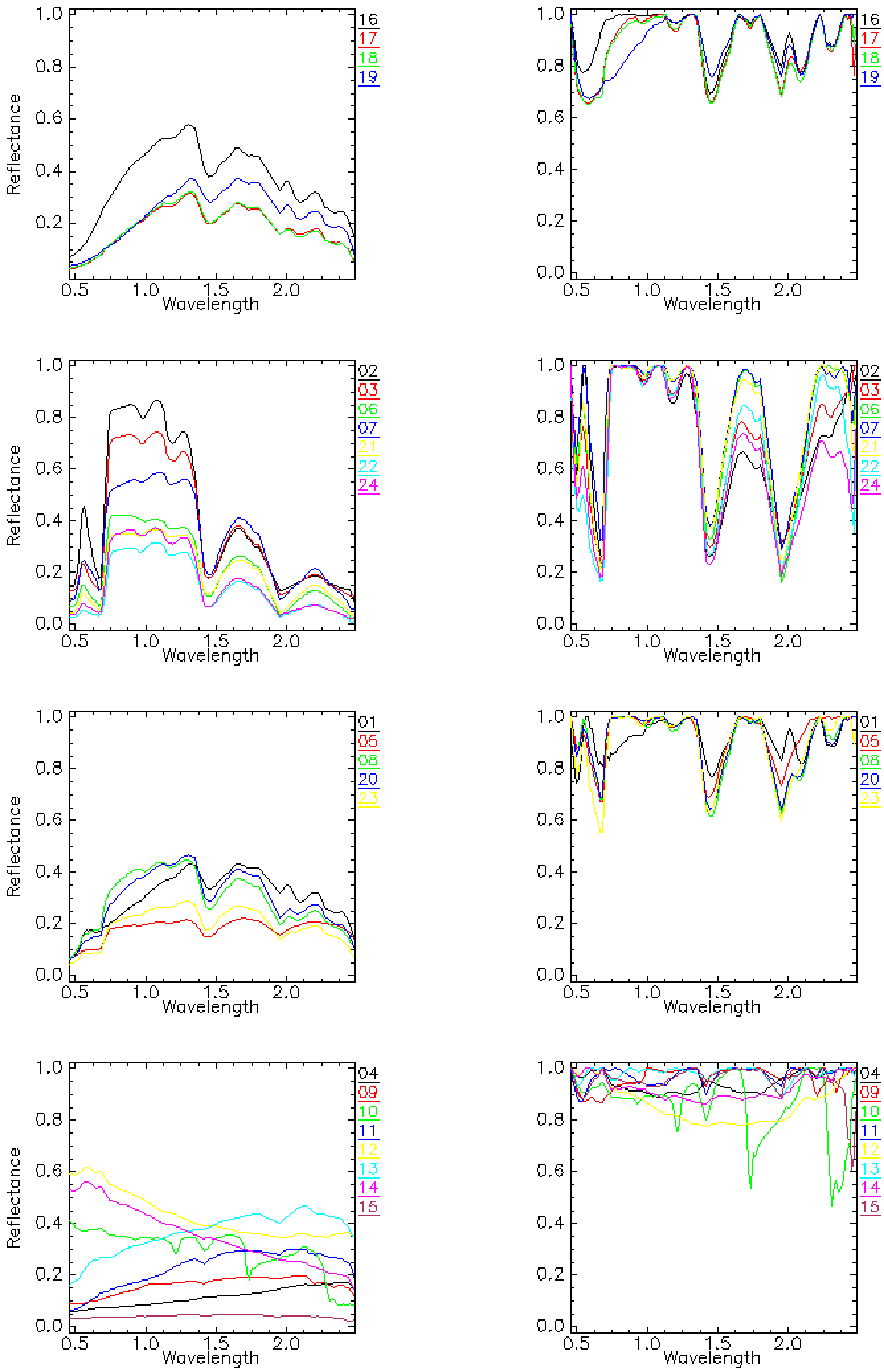
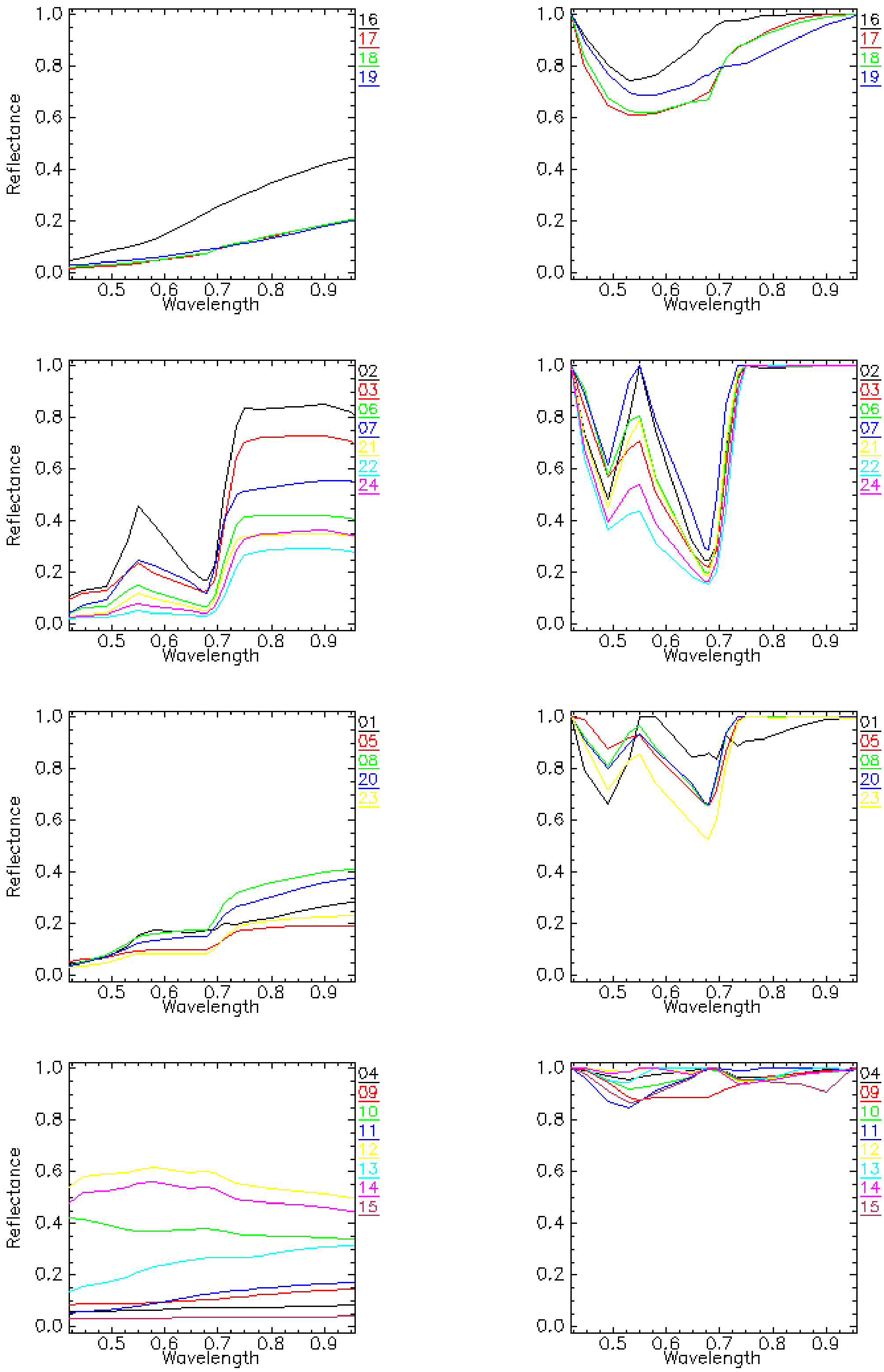


Plate 4 ASD spectra resampled to CASI band range, reflectance and continuum removed



ASD 17 and 18 are both spectra of American vetch. ASD 17 visibly showed a slightly yellow tinge compared to the drier appearance of ASD 18. These spectra are not separable from each other with either the HyMap or CASI spectral range, but *A. americana* appears spectrally distinct from the other dried weed types measured (ASD 16 and 19) with the HyMap spectral range. ASD 17, 18 and 19 are not spectrally distinguishable with the CASI resolution. ASD 16 (Black speargrass) shows a greater magnitude in reflectance compared to ASD 17, 18 and 19 in both the HyMap and CASI ranges. ASD 19 shows a red edge at longer wavelengths than the other dried grasses with both the HyMap and CASI wavelength range. The CR profile is required to visualise this absorption difference in the CASI data.

The CR profile highlights that the green vegetation spectra (ASD 2, 3, 6, 7, 21, 22, and 24) show similar absorption positions. Despite this, these spectra may be separable based on their differences in reflectance magnitude in both the CASI and HyMap data range.

ASD readings 1, 5, 8, 20 and 23 are characterised by similar absorption features in the CR including 0.49 and 0.67 μm in the VNIR. The 0.49 μm feature is strongest in ASD 1 and 23, and least in ASD 5, as illustrated in the CR profile. This absorption feature in the blue region is much broader and deeper for ASD 1. The 0.67 μm absorption in the CR profile is strongest in ASD 23, very similar in ASD 5, 8 and 20 and least in ASD 1. ASD 5 and 23 show similar reflectance curves. ASD shows additional unique features in the VNIR region.

ASD readings 12, 13, and 14 representing different concretes, ASD 10 (white PIF), ASD 15 (black PIF), and ASD 4 (ash) are potentially distinguishable based on their reflectance magnitude in both the HyMap and CASI range data. ASD 9 (schist) and ASD 11 (iron-rich gravel and ash) are potentially separable with their increase in reflectance at longer wavelengths in the near infrared, as well as the iron absorption for ASD 11.

5 Discussion

Field-based spectral measurements of land cover features, including selected native and introduced plant species, were acquired at Nabarlek. However, due to time constraints not all vegetation species or land cover components of the study area were characterised. Additionally, the method of collecting vegetation spectra varied; for example, with respect to grasses a vertical spectrum was made, while for trees (Acacia And Melaleuca) only leaf spectra were acquired. Despite the limited number of spectra measured, it was useful to gain understanding of the reflectance and continuum removed profiles for potential separability of a range of vegetation types.

At the time of field spectral collection, native Black speargrass and the invasive weed American vetch were senescent and brown in colour. Paragrass and Couch grass were senescing and turning yellow in colour. In contrast, Acacia and Melaleuca leaves were green. The full wavelength ground-based spectra for the dry, green, and yellowish vegetation appear separable based on the positioning of absorption features. Resampling these to CASI wavelengths showed that CASI data should distinguish between green, dried and yellowing vegetation. However, there is some uncertainty as to whether individual species from the field spectra will be separable with the CASI wavelength range based on subtle differences in reflectance magnitude.

Separability of Melaleuca and Acacia species from the ASD spectra would not be achieved because the ASD spectral measurements were of leaves and not full canopies. However, at the time of image capture, Acacia trees present on the minesite were flowering. Visually, Acacia trees appear separable from other trees in the CASI image because of the spectral contribution from their yellow flowers.

Visually, the effects of recent fires on the vegetation at the Nabarlek site were apparent in the CASI data. There were also marked differences between the minesite and surrounding vegetation cover. In particular, the CASI data showed sparse patterns of vegetation cover on the old mine pit, waste rock dump, evaporation ponds, stockpile runoff pond and ore stockpile. The dense grass cover associated with the moist area of the plant runoff pond was an exception.

5.1 Limitations in spectral sampling

The ADS was hired for one day’s work at the Nabarlek site, including travel to and from Jabiru to the site. A major aim of the spectral measurements was to record the reflectance of potential PIFs for empirical atmospheric calibrations of the airborne sensor with relative ground reflectance.

It would be extremely useful to perform more intensive temporal ground-based spectral measurements for vegetation characterisation. A temporal spectral library would need to be gathered in order to answer such questions as:

Is the component spectrally unique?

What is the spectral resolution required for detection?

What spatial resolution is required for detection?

What is the best time of year/day for spectral discrimination?

What signal-to-noise ratio is required for detection?

To date, there are few vegetation spectral libraries. None are comprehensive or relating to tropical vegetation. The creation of such a library would be a large task. Reflectance of different vegetation (including leaves, stems, flowers, background soil) at periods of phenology would be required. Information on spectral changes with seasonality would provide necessary insight into optimal timing of image capture for the discrimination of priority land cover features from remotely sensed data.

Aside from remotely sensed data, field spectral measurements can be used to make direct material identifications in the field rather than collecting samples for later laboratory analysis. Such examples include mineral identification, and various vegetation characterisations including: relative chlorophyll, moisture content, health, vigour, stress, senescence and metal uptake, all of which are useful in expressing rehabilitation success.

6 Future work

Future work will document CASI image based mapping and test mapping algorithms for comparing field-based spectra to CASI image spectra.

Field-based transects, recording density of each plant species, phenology, height and percentage cover has been implemented. Once complete, this information will contribute to accuracy assessments. This work is part of an assessment of the use of remote sensing for minesite rehabilitation assessment at Nabarlek. As the CASI image capture was opportunistic, Quickbird satellite data will be captured at the time of transect field-based sampling. Ground and satellite data capture will be repeated in the late wet season in order to make recommendations for the best time of image data capture to differentiate vegetation structure and composition of the site and surrounds.

A cost effective benefit comparison with a variety of remotely sensed data and field-based techniques will then be performed.

7 Appendix – field data

Location description	Easting	northing	Asd reading #	Photo #	Time	Sample collected	Notes (including any cloud cover, wind, sun angle to reading changes)
Mixed dry weedy grasses & herbs along roadside.	316928	8639058	S001 x 8	682 x3	11.29	1. Paragrass and Hyptis	Reading taken looking S out of mine. Mod wind. Reading vertical from above.
Melaleuca alongside road.	316923	8639061	S002 x 4	x2	11.38	2.	Moderate wind facing S. Older leaves.
Melaleuca alongside road	316924	8639060	S003 x 5	x1	11.40	3.	Very windy facing S. Young leaves
Ash – dark	316920	8639068	S004	1 general	11.42		Facing S
Ash with green grass	316920	8639072	S005 x 7	As above	11.44		Facing E
Green grass	316925	8639069	S006 x 8	1	11.46		Facing E
Long grass – green leaf	316923	8639078	S007 x 5	1	11.47		Facing E. Green leaf held at an angle
General overview from above ~ 0.5m above of sample S007	As above	As above	S008 x 10		11.49	4 Introduced pasture grass – Paragrass	Facing E
				Change cameras			
Schist outcrop	316908	8639084	S009 x 7	1	12.00	-	Strong wind. Bright grey schist with Fe hue
White PIF	316332	8639529	S010	1	12.10	-	Windy. Facing E
Background to PIF – mixed	Varied around edge of PIF		S011 x 10	1	12.14	-	Averages taken around PIF with sun over left shoulder
LUNCH							

Concrete slab west	1 – 317691 8639340 (SW) 3 – 317684 8639363 (NW) 2 – 317685 8639341 (SW) 4 – 317689 8639363 (NE)		S012 x 7	2			Pointing N
Concrete slab east - light brown	317822	8639363	S013 x 12				East – raw (no paint) GPS reading to middle of Nth half
Concrete slab east – paint	317792	8639353	S014 x 11				
Black PIF	317796	8637968	S015 x 10	1	14.43	-	No wind
Black Spear grass (native)	317798	8637978	S016	1	14.45	5. Black speargrass	No wind. Grass next to PIF.
Weed 01	317777	8637978	S017 x 10	32	14.47	6. American vetch	Greenish tinge to dry weed. Facing N
Weed 02	317767	8637978	S018 x 10	31	14.50	-	Same weed as S017, but drier. Same pod. Facing N
Weed 03	317764	8637974	S019 x 10	33	14.53	-	Dry grass clump
Weed 04	317765	8637974	S020 x 10	30	15.00	7. Couch grass	Low grass~ 10 cm high. Yellowy green colour
Weed 05	317676	8637991	S021 x 10	1	15.10	8. Passionfruit vine	2@ 1m height 2@ ground level. Green vine. Looks like passion fruit
Weed06	317680	8638000	S022 x 10	1	15.15	9. Siratro	Darker green (than above) vine with purple-red flowers
Weed07	317672	8637994	S023 x 8	1	15.20	-	Green grass - ~5cm high. Clumps
Acacia	317683	8638015	S024	1	15.33	10	Small leaves (1 cm wide x 14cm long) green. Tree ~ 2m high.

5 degree FOV. 06/08/02

Characterisation of Nabarlek minesite using CASI data

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ABSTRACT

Important but subtle changes in land surface features detected by remotely sensed data with high spatial, spectral and radiometric resolutions may be required to monitor environmental impacts of active mine sites and determine the success of their eventual rehabilitation. Compact Airborne Spectrographic Imager (CASI) data were acquired over the rehabilitated Nabarlek uranium mine in northern Australia to assess its potential for characterisation of the minesite, and is part of a larger, long-term environmental study. The major aims of the CASI study were to help assess whether or not vegetation communities on the minesite blended with the undisturbed surrounding landscape, and to contribute to a quantitative description of the plant communities in the Nabarlek region. The survey captured 19 spectral bands across the VNIR region of the spectrum at 1m spatial resolution. Field-based spectrometer readings were acquired to support image reflectance conversion and to assess the feasibility of spectral discrimination for selected land cover features, including mining-related infrastructure, plants (weeds & native vegetation), fire scars and soils. CASI data highlighted infrastructure features such as the rehabilitated waste rock dump, mine pit area, evaporation ponds and remnant buildings. There were marked differences in vegetation between the rehabilitated site and surrounding landscape, particularly the greater abundance of *Acacias* on-site. In summary, CASI data contributed to an assessment of revegetated areas on the Nabarlek minesite and showed promise as a monitoring and assessment tool for rehabilitated mine sites in general. Future work will include an analysis of image data alone and an assessment of a HyMap data capture.

Introduction

One of the major issues facing both the mining industry and regulatory bodies is the development of methods for assessing the success of minesite rehabilitation. Such methods are needed to determine the point at which intervention is required to obtain rehabilitation goals, and eventually whether or not the mining company has fulfilled its obligations (Allan 1992). Unfortunately, there are no quantitative industry standards to assess revegetation (Corbett 1999), a critical component of rehabilitation success.

The Nabarlek minesite in the Northern Territory was the first uranium mine to be rehabilitated in Australia under a contemporary regulatory regime. The work described here is part of a long-term study of the rehabilitated Nabarlek site by the Supervising Scientist Division of Environment Australia. One research component of the Nabarlek study is to assess the success of revegetation on the rehabilitated site.

Traditionally, revegetation assessment is performed using field-based point checks. At Nabarlek, Earth Water Life Sciences (EWLS) have been undertaking annual photo-point monitoring of vegetation to assess revegetation success (Welch and Gibson 2002). The procedure involves the collection of photographs and observations at designated points for vegetation condition, surface stability and feral animal activity.

More rigorous ecological-based assessments involve comparisons of rehabilitation areas with target communities outside the mining lease (reference areas or analogs), including detailed descriptions of vegetation characteristics such as species abundance, diversity, structure and growth. Such methods

usually involve the establishment of grids, transects, or quadrants to collect statistically valid data that can be used to compare vegetation communities between rehabilitated and reference sites. Examples of recently-developed methods include Ecosystem Function Analysis (EFA) (Tongway *et al.* 1997) and Vital Ecological Attributes (VEA) (Aronson and Le Floc'h 1996).
The disadvantage of traditional field-based assessment is that they are labour intensive and may become cost-prohibitive when applied to large areas given the frequency of assessment that may be required. In addition, they sample only a small proportion of the area affected by mining and are certainly not a holistic approach for the mining lease and surrounds. The qualitative nature of many methods may also cause problems with consistency when used by different assessors (Corbett 1999).

Remote sensing techniques cannot replace all measurements required for minesite rehabilitation assessment. However, they can potentially determine current (baseline) conditions, feed into rehabilitation and monitoring assessments, and detect potential problems of a site that may be missed by field-based sampling.

Minesite monitoring and rehabilitation assessment over small landscape scales may often require high spatial and spectral resolutions. In this paper we use Analytical Spectrometer Device (ASD) ground-based reflectance data of a number of land cover features on the Nabarlek site to assess the usefulness of Compact Airborne Spectrographic Imager (CASI). This paper provides an initial assessment of the data suitability for determining the success of revegetation of the Nabarlek minesite area.

This paper provides insight into the spectral characteristics of selected vegetation types over the Nabarlek minesite at the time of CASI image capture. This paper describes the potential separability of field based vegetation spectra. Reflectance and continuum removed spectral curves are visually assessed to highlight differences in the overall reflectance shapes and absorption feature positions and depths of field spectra. Ground-based spectra are compared with image spectra using a Spectral Angle Mapper algorithm. This paper does not highlight image based mapping techniques alone. Future work will document image based mapping and test other mapping algorithms. Comprehensive ground-based transect sampling measuring woody plant density and herbaceous cover has been implemented. Once complete, this information will contribute to accuracy assessments. This work is part of an assessment of the use of remote sensing for minesite rehabilitation assessment at Nabarlek. This CASI image capture was opportunistic. Quickbird satellite data will be captured at the time of transect field-based sampling.

Study Area description

The rehabilitated Nabarlek uranium mine is situated in Arnhem Land about 270km due east of Darwin (Figure 1). The climate is characterised as “summer monsoonal”, with an annual average rainfall of 130cm, of which 110cm falls between December and March (Anthony 1975). The Arnhem Land Plateau, comprised of coarse-grained sandstone, dominates the steep escarpment landscape surrounding the Cooper Creek plain area in which Nabarlek is situated.

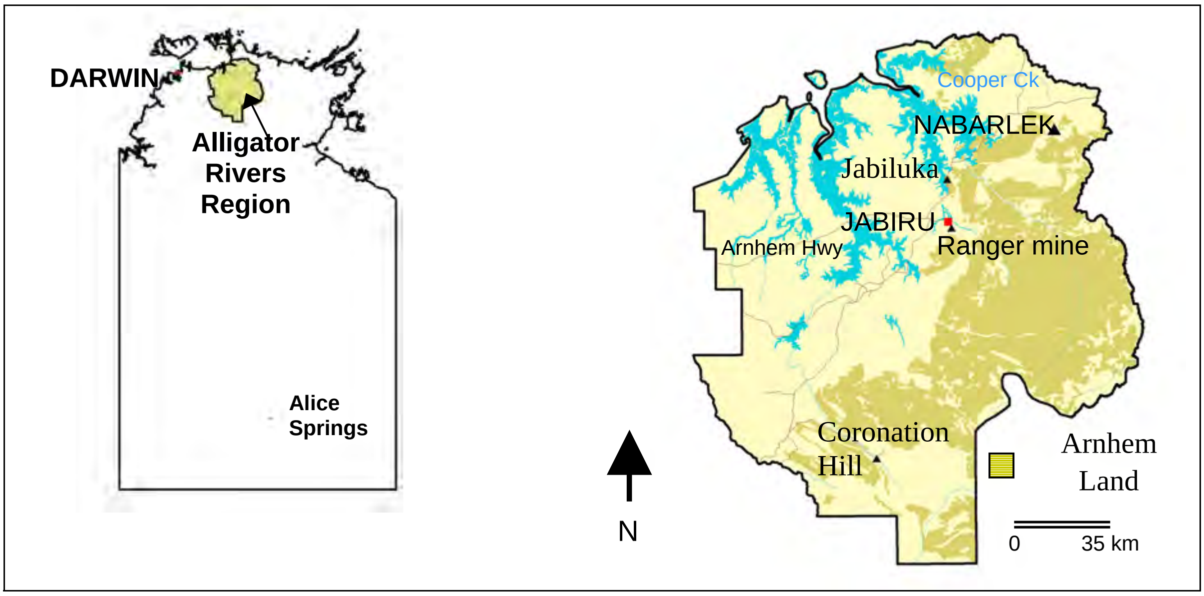

Figure 1 Location of the Nabarlek minesite in the Alligator Rivers Region

Near-surface uranium mineralisation was discovered by Queensland Mines in June 1970. Most of the ore was at a depth less than 45m (Battey *et al.* 1987). The grade variation within the orebody was extreme (ranging from 0.1 to 72 per cent U_3O_8). A total of 600,000 tonnes of average 2% grade ore were stockpiled and subsequently milled with uranium oxide being sold from 1980 to 1988 (UIC 1997). The mine was decommissioned in 1994.

Major rehabilitation and decommissioning works were completed at the end of 1995. Revegetation was undertaken by Queensland Mines, and was expected to blend with the surrounding landscape. In 2002, all of the revegetated areas were dominated by *Acacia* spp with an average height of about 5–8m, with many trees having been damaged or killed by fire over the previous two dry seasons (Welch and Gibson 2002). Substantial infestations of Para grass (*Brachiaria mutica*) are present on the site, particularly around the former evaporation pond area. Other weed species include mission grass (*Pennisetum polystachion*) and hyptis (*Hyptis suaveolins*). Ground covers of native grass include *Sorghum* spp, and native perennial grass *Heteropogon* sp. The pit area is relatively open and has very poor ground cover (Welch and Gibson 2002).

Data acquisition

CASI data at 1m spatial resolution, covering the visible near-infrared (VNIR) region of the spectrum, were acquired over the Nabarlek area on 7th July 2002 (commissioned to Ball AIMS). The survey was flown at a height of 750m, capturing 1m pixel resolution. Approximately 600 ha of data were flown in a NW-SE direction. Three lines of data were flown, deliberately covering undisturbed mining areas to aid in revegetation assessment. Nineteen bands of the VNIR portion of the spectrum were acquired, covering the visible blue to the near-infrared region of the spectrum (refer to Table 1).

ASD ground-based reflectance data of a number of land cover features on the Nabarlek site were captured on the 6th August 2002. ASD reflectance measurements were recorded to aid in the atmospheric correction process of airborne CASI data and to spectrally characterise a number of land cover features (e.g. vegetation, fire scars, soils, rocks). Measurements in the range 350 – 2500nm were acquired. Photographs, GPS readings and ancillary notes were made for each spectrum acquired. Specimens of plants that could not be identified were collected for the herbarium. The one month delay between remotely sensed and field-based data capture was a result of site inaccessibility. Selected vegetation types, particularly weed species, were sampled and their spectral separability determined.

Ball AIMS performed baseline data processing, including radiometric, navigation, geometric correction and the production of an image mosaic. The Environmental Research Institute of the Supervising Scientist (***eriss)*** supplied a high resolution DEM of the site to aid the orthorectification process.

Table 1 Spectral Characteristics of the CASI data

Band #	Wavelength (nm)	FWMH	Band #	Wavelength (nm)	FWMH
Band 1	419.000000	13.20	**Band 11**	710.500000	6.00
Band 2	443.899994	11.40	**Band 12**	733.400024	6.00
Band 3	490.200012	11.60	**Band 13**	748.799988	6.00
Band 4	529.400024	7.80	**Band 14**	780.400024	8.00
Band 5	549.099976	6.00	**Band 15**	800.599976	9.80
Band 6	578.299988	7.80	**Band 16**	850.500000	9.80
Band 7	646.599976	4.20	**Band 17**	900.500000	9.80
Band 8	671.299988	8.00	**Band 18**	950.400024	9.80
Band 9	678.900024	4.20	**Band 19**	957.099976	4.20
Band 10	693.299988	6.00			

Methods

ASD measurements of native vegetation included: *Melaleuca* sp. leaves; dry *Heteropogon* sp. grass; green *Pseudoraphis* grass; and *Acacia* sp. leaves. Spectra of weed species included: *Aeschynomene americana* (greenish-dry and dry spectra); *Passiflora foetida; Macropitilum atroppurpureum* (siratro); *Urochloa* sp. (liverseed grass); and mixed ground cover comprised of *Brachiaria mutica* (Para grass), and *Hyptis suaveolens*. Observations on the growth form of *P. foetida* and *M. atroppurpureum* indicated that they would not be identifiable from the remotely sensed data. However, as these weed species are known to colonise and cover large areas rapidly, their signatures were measured for potential future studies. Fire scar spectra comprised dark ash and ash mixed with green grass.

Pseudo-invariant features (PIFs) were laid in the field prior to image capture and ground-based spectral readings were made to aid the atmospheric correction process. White and black 50% shadecloth were used as light and dark PIFs, respectively. Four m^2 shadecloth was pegged and laid flat on patches of gravely iron-rich sediment in the study site. In addition to spectral measurements of shadecloth, large slabs of concrete (including bright, white painted concrete) were also measured for PIF suitability. The vicinity of the PIFs were also recorded.

Spectral averages of ASD classes were evaluated for spectral similarity (within classes) and the total number of spectra for each endmember was then averaged. The 1.356 – 1.417μm and 1.778 – 1.953μm regions were excluded due to their contributions to atmospheric noise. Each profile was visually analysed and described as reflectance and continuum removed in order to determine the potential spectral separability of the land cover features measured. The shape of the profile, absorption feature position and depths were described. These spectra were then used as an input into the CASI processing.

The empirical line calibration technique was used to compensate for atmospheric interference and to convert the CASI data from radiance to reflectance values. The lowest and highest field-based reflectance across the VNIR wavelengths were provided by the black shadecloth and white painted concrete. These PIFs were suitable for the empirical line technique, as they are spectrally flat and easily identifiable in the airborne image.

Spectral Angle Mapper (SAM) was used to compare image spectra to the ground-based spectra. SAM uses an algorithm that determines the similarity between two spectra by calculating the spectral angle between them and then treating each as vectors in space with dimensionality equal to the number of bands (Kruse *et al* 1993). The angle between the endmember vector and each pixel vector is compared, where smaller angles represent closer matches to the reference spectrum. The measure of similarity is insensitive to instrumental and other gain factors because the angle between the two vectors is invariant with respect to their lengths, with intensity being a value in that wavelength region. The length of the vector relates only to how fully the pixel is illuminated. For each reference spectrum chosen in the analysis, the spectral angle is determined for every image spectrum. This value is assigned to the corresponding pixel in the output image. When used on calibrated data, SAM is relatively insensitive to illumination and albedo effects, as the method uses only the vector direction of the spectra and not their vector length (Kruse and Huntington 1996).

The top 10% SAM results at 1% intervals were used as a threshold. Mean spectral profiles of the threshold were then compared to the field-based readings (with reflectance and continuum removed) to assess their spectral match. Additional verification of mapping results was made using a combination of prior knowledge and visual inspections. Ground based transect sampling will provide more thorough accuracy assessment.

Results

A visual analysis of the reflectance and continuum removed spectral curves highlighted the differences and similarities in the reflectance of land cover features sampled. Although the general shape of the spectral curve is similar for all green vegetation, changes in reflectance may occur through variations in amplitudes of the curve between different species. Slight differences in chlorophyll and water absorption position and depth may also occur. Vegetation stress, senescing and desiccation all produce changes in the spectrum that may be subtle between like vegetation. The field spectra were therefore grouped and their spectral characteristics observed at the full wavelength range and resampled to the CASI wavelengths. Groups of vegetation included green vegetation, yellowing vegetation and drying vegetation. Comparisons within and between these vegetation groups were made to assess whether the field spectra were potentially spectrally separable, both between vegetation groups and for species within groups.

Dried vegetation was represented by *Heteropogon* sp. and *A. americana*. In general these spectral profiles showed an obvious loss of chlorophyll absorption, an increase in reflectance to the near-infrared with 1.42, 1.95µm (water), 2.0µm absorptions and a very slight 1.73µm absorption (Figure 2). Slight reflectance differences in the visible were observed. *Heteropogon* sp. was characterised by a higher magnitude in reflectance and showed an increase at 0.46µm and a very minor absorption centred at 0.50µm. *A. americana* had a broader shallow absorption centred at 0.51µm. For the CASI wavelengths, these species were distinguishable by a greater magnitude in reflectance for *Heteropogon* sp. (Figure 2).

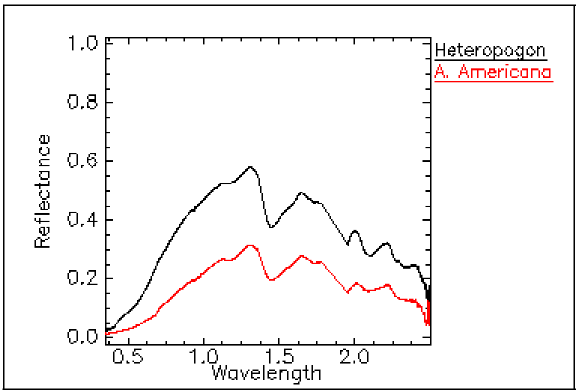

Figure 2a. Full spectra reflectance

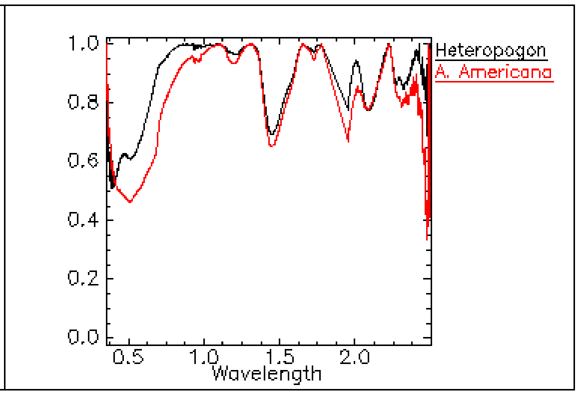

Figure 2b. Full spectra continuum removed

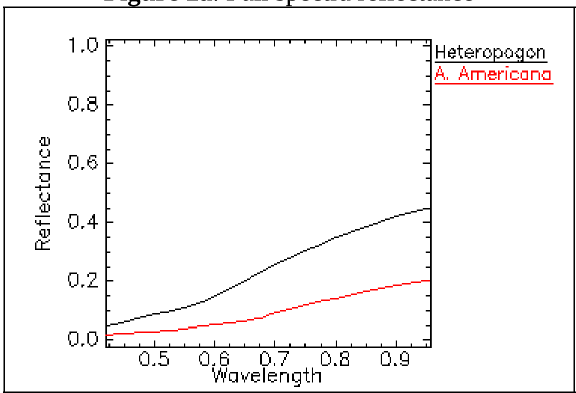

Figure 2c. Spectra (resampled to CASI) reflectance

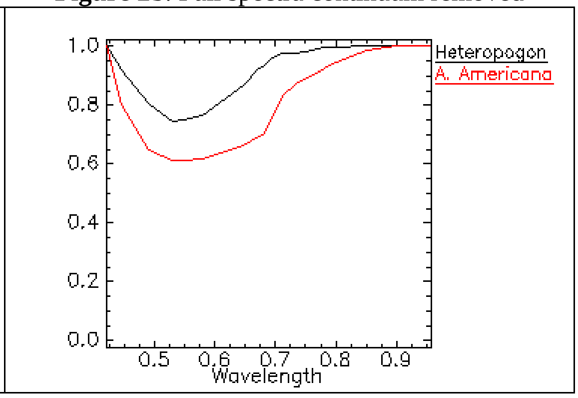

Figure 2d. Spectra (resampled to CASI) continuum removed

Figure 2 Dried vegetation spectra

Full spectra: reflectance (Figure 2a), continuum removed (Figure 2b). Spectra resampled to CASI wavelengths: reflectance (Figure 2c) and continuum removed (Figure 2d).

Green vegetation spectra corresponded to *Melaleuca* sp., *Urochloa* sp. (green), *P. foetida*, *M. atropurpurem* (sirato) and *Acacia* sp. leaves (Figure 3). All spectra had chlorophyll absorptions around 0.50 and 0.67µm. The red edge increased to a maximum reflectance at ~ 0.74µm for these spectra. Slight 0.96 and 1.81µm absorptions and stronger absorptions at 1.42 and 1.95µm also occurred (Figures 3a-b). The continuum removed profile highlighted that the green vegetation spectra showed similar absorption positions. Nevertheless, these spectra may be separable based on their differences in reflectance magnitude. Although the general shape of the spectral curve was similar for all green vegetation, variations in the amplitudes and positioning of features were observed. The "blue" chlorophyll absorption was at slightly shorter wavelengths for *Melaleuca sp.* and green *Urochloa* sp. (0.49µm rather than 0.50µm). *Passiflora*, sirato and *Acacia* leaves show stronger blue absorptions compared to the other green vegetation spectra (Figure 3d). The chlorophyll absorption in the red region at 0.67µm was strongest for sirato, *Acacia* leaves, green *Urochloa* and *Passiflora*. The red-edge shift was at shortest wavelengths for green *Urochloa* and at longest wavelengths for sirato. *Melaleuca* leaves displayed the greatest reflectance magnitude in the green and near-infrared, followed by green *Urochloa*. Sirato displayed the lowest magnitude red-edge shift at longer wavelengths.

The *Melaleuca* signature appears most separable, based on the spectrum's higher magnitude of reflectance and strong chlorophyll absorption. There is more uncertainty as to whether or not the other green vegetation types are separable at the CASI wavelength ranges. *Passiflora* and sirato are not expected to be identifiable in the CASI data, based on the growth form of these plants.

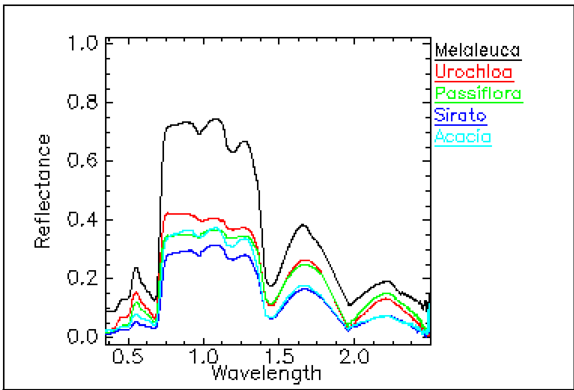

Figure 3a. Full spectra reflectance

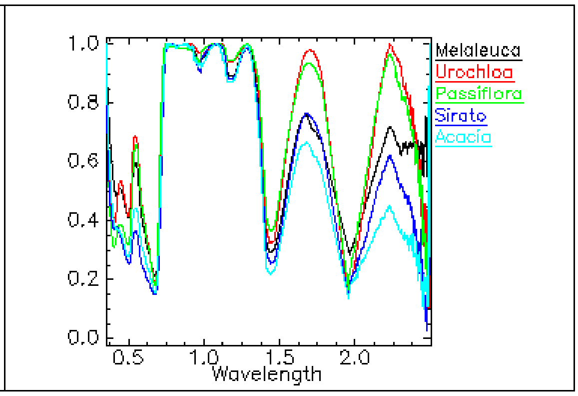

Figure 3b. Full spectra continuum removed

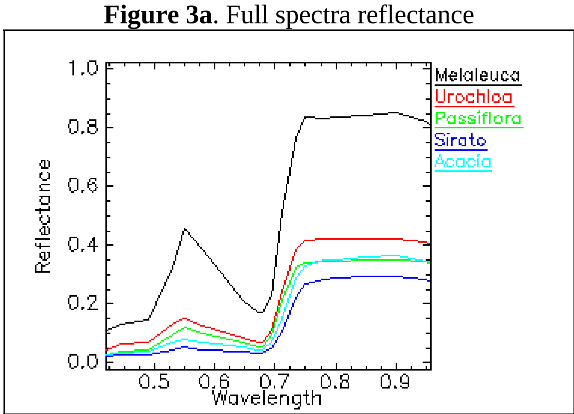

Figure 3c. Spectra (resampled to CASI) reflectance

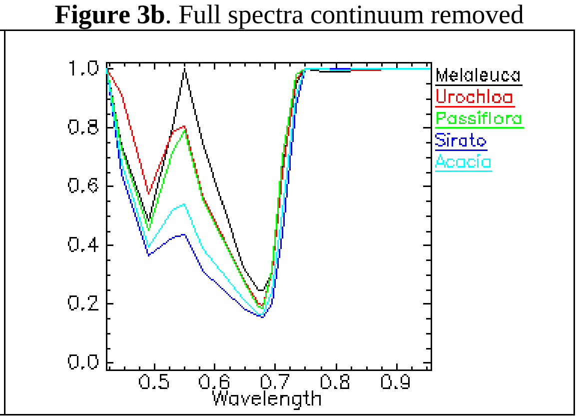

Figure 3d. Spectra (resampled to CASI) continuum removed

Figure 3 Green vegetation spectra

Full spectra: reflectance (Figure 3a), continuum removed (Figure 3b). Spectra resampled to CASI wavelengths: reflectance (Figure 3c) and continuum removed (Figure 3d).

Mixed grasses (*Brachiaria mutica* and *Hyptis suaveolens*), *Urochloa* sp. (drying) and *Pseudoraphis* sp. represent less green vegetation (yellowing) (Figure 4). *Urochloa* (drying) was a mixed reflectance of the green and dried grass. The mixed signature showed much less chlorophyll absorption in the blue and red regions, and a red-edge shifted to longer wavelengths compared to the green *Urochloa*. *Pseudoraphis* showed a loss of chlorophyll absorption compared to the green vegetation, but maintained distinct absorptions in the reflectance curve at 0.49 and 0.67µm. These spectra were characterised by similar absorption features in the continuum removed profile (Figures 4b and 4d) including 0.49 and 0.67µm in the VNIR. The 0.49µm feature is strongest in the mixed grasses and grass class. This absorption feature in the blue region is much broader and deeper for mixed grasses. The 0.67µm absorption in the continuum removed profile is strongest in the grass class, very similar in *Urochloa* (dry) and *Pseudoraphis* and least in the mixed grasses.

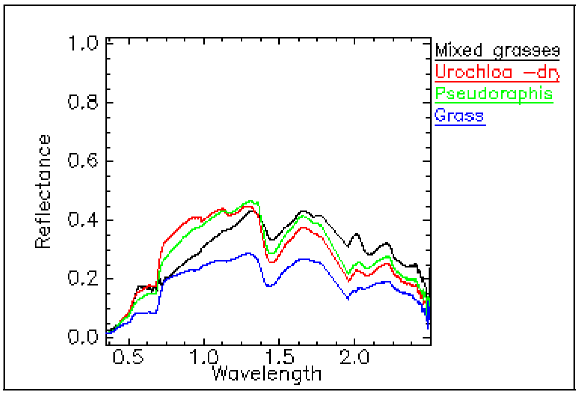

Figure 4a. Full spectra reflectance

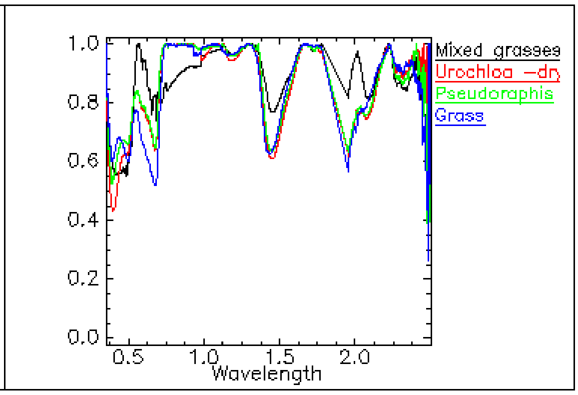

Figure 4b. Full spectra continuum removed

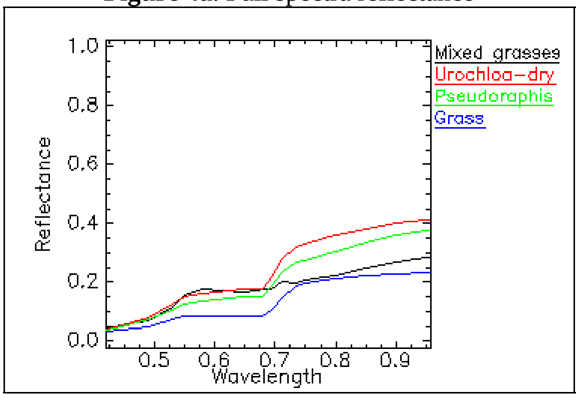

Figure 4c. Spectra (resampled to CASI) reflectance

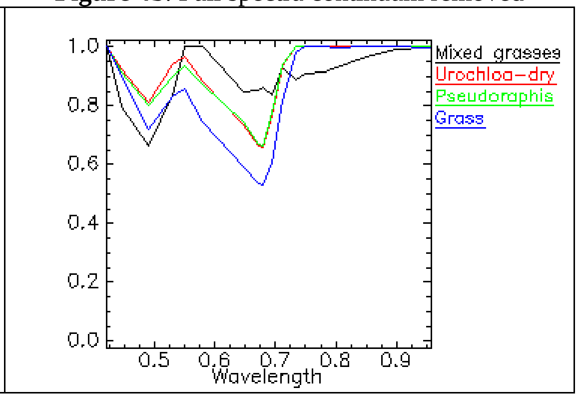

Figure 4d. Spectra (resampled to CASI) continuum removed

Figure 4 Green vegetation spectra

Full spectra: reflectance (Figure 4a), continuum removed (Figure 4b). Spectra resampled to CASI wavelengths: reflectance (Figure 4c) and continuum removed (Figure 4d).

White shadecloth, bluish concrete, brownish concrete, white concrete and black shadecloth were measured as potential PIF targets for empirical line atmospheric calibration. Absorptions shorter than 0.43µm were of no concern as this region is outside the atmospheric window region. Black shadecloth showed a fairly flat, featureless and low reflectance curve across the visible – near-infrared, indicating that the black shadecloth is a reasonable calibration target. The reflectance characteristics of the white shadecloth did not make a good calibration target, with 0.54μm absorption and a broad shallow 0.8-0.9μm absorption. The later is probably due to the iron-rich gravel underneath the 50% shadecloth contributing to the reflectance. SWIR absorptions occurred at 1.21, 1.41, 1.73 and 1.76μm. White concrete provided an alternative calibration target of high reflectance, despite a minor absorption around 0.50 and 0.64μm.

The iron-rich gravel with ash reflectance curve shows an increase from the visible to 1.35μm, with the continuum removed curve showing absorptions at 0.512 and a broad iron absorption from 0.8 – 1.1μm. This spectrum is also characterised by hydroxyl and clay absorptions at 1.41, 1.95 and 2.20μm.

Figure 5 shows the true colour RGB (bands 7 5 2) CASI mosaic. Mining features (old evaporation ponds, stockpile runoff pond, mine pit, waste rock dump and plant area) are clearly identifiable. The west arm of the Cooper Creek traverses the survey area to the southeast of the mine and Kadjirrikamarnda Creek to the north west of the mine.

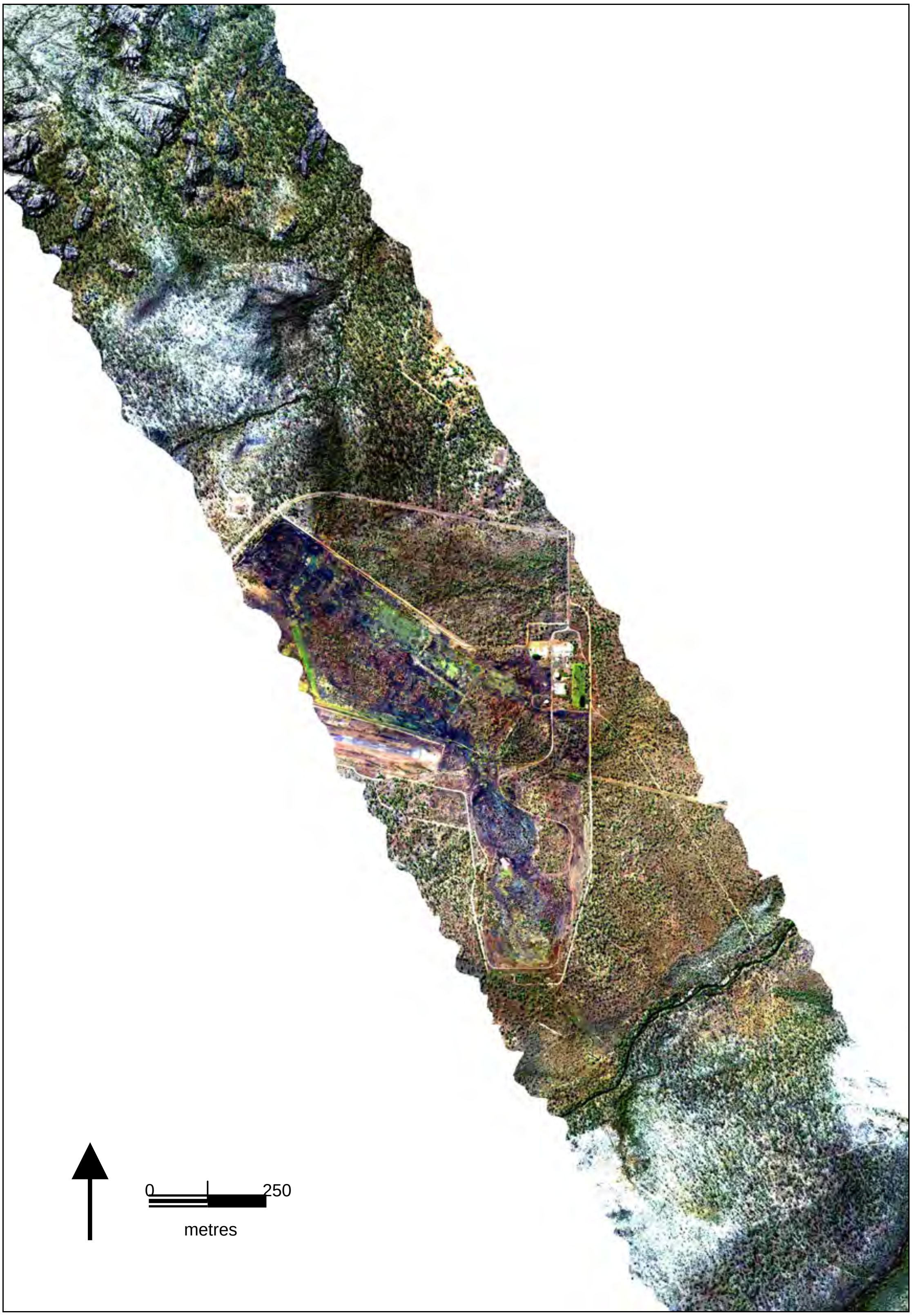

Figure 5 "True Colour" CASI data (bands RGB)

Figure 6 is a false colour subset of the CASI data (infrared, red, and green, bands 15, 8, 6) with vector mining features, roads and streams overlaid on 1:50 000 topographical data to illustrate the orthorectified product.

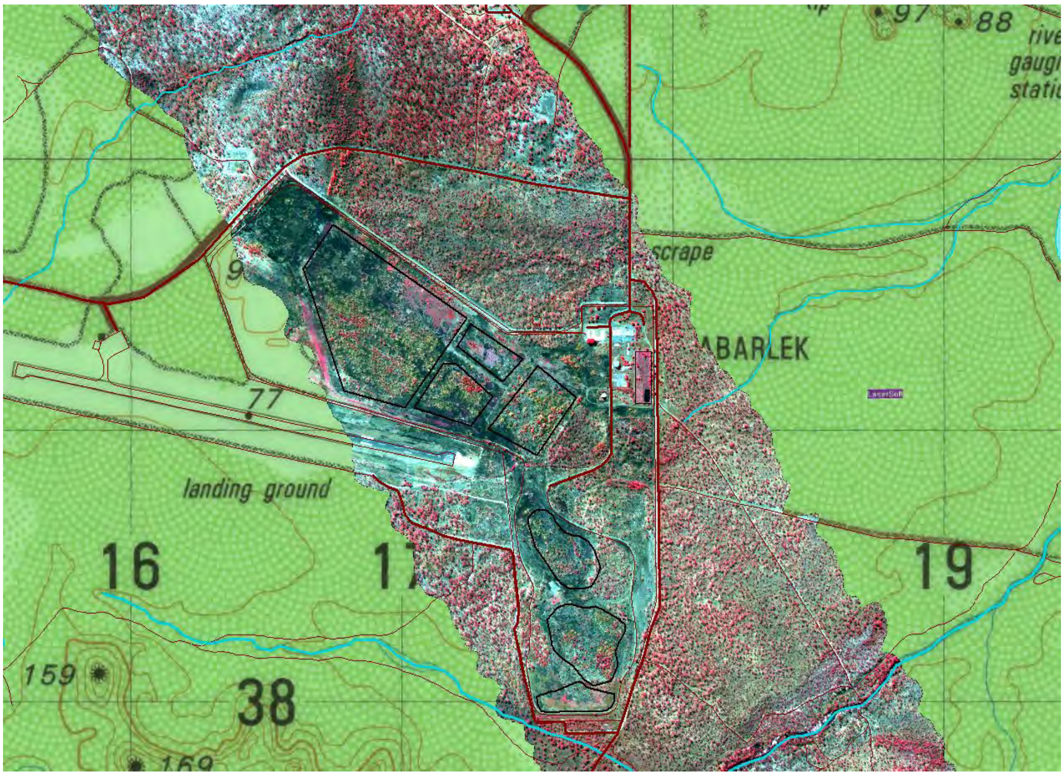

Figure 6 "False Colour" Subset of CASI data (bands 15, 8, 6) with vector mining features, roads and streams overlaid on 1:50 000 topographical data

A threshold of the lower spectral angles was used to create SAM maps. Threshold cut-offs were based on mean spectral profile similarities at 1% intervals, combined with a prior knowledge of the spatial location of the cover type. Figure 7 (a subset of Figure 6) and Figure 8, covers the old plant area, plant runoff pond and part of the evaporation ponds. Figure 8 provides a subset of SAM mapped results. As an example, "green tree vegetation" SAM threshold 97-100% is displayed on a greyscale image. Figure 7 provides a visual comparison for Figure 8 and demonstrates that individual tree canopies can be differentiated.

Figures 9-15 graphically compare the SAM high percentage pixel spectra to the field spectra for selected vegetation types. Figure 9 graphs the 96-100% results of the SAM mapping for *Heteropogon*. The ground spectra shows a higher magnitude of reflectance compared to the mapped image pixels. The VNIR absorption feature corresponds well. Spatially, these pixels correspond to dried grasses.

Figure 10 illustrates the 97-100% threshold of the SAM mapping for *Melaleuca* leaves. Figure 11 graphs the 98-100% threshold for green *Urochloa*. Absorption features fit, although a greater magnitude in reflectance is seen by the ground-based spectra in both figures 10 and 11. A fit between image *Acacia* leaves and ground-based spectra is provided by the 96-100% SAM results (figure 12). Spatially, these pixels correspond to green tree canopies.

Figures 13-14 graph the yellowing vegetation results. The depth of absorption features and reflectance magnitude differs for the ground-based and image spectra. A spectral feature fitting over the visible absorption region may be required to map this vegetation type.

Figure 15 illustrates the 98-100% SAM results of green grass, illustrating a fit for ground and image spectra in the reflectance profile.

Figure 7 "True colour" subset of CASI data, bands 7 , 5, 2 (RGB) covering the old plant area, plant runoff pond and part of the evaporation ponds.

Figure 8 SAM "green tree" 97-100% results
For comparison with green tree locations in Figure 7.

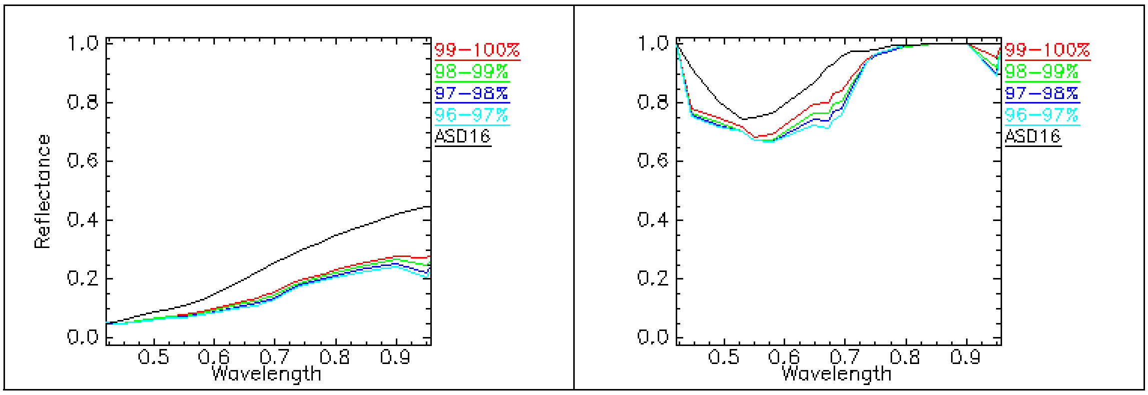

Figure 9. ***Heteropogon*** **SAM results 96-100% top threshold plotted against ASD spectra. Reflectance and continuum removed.**

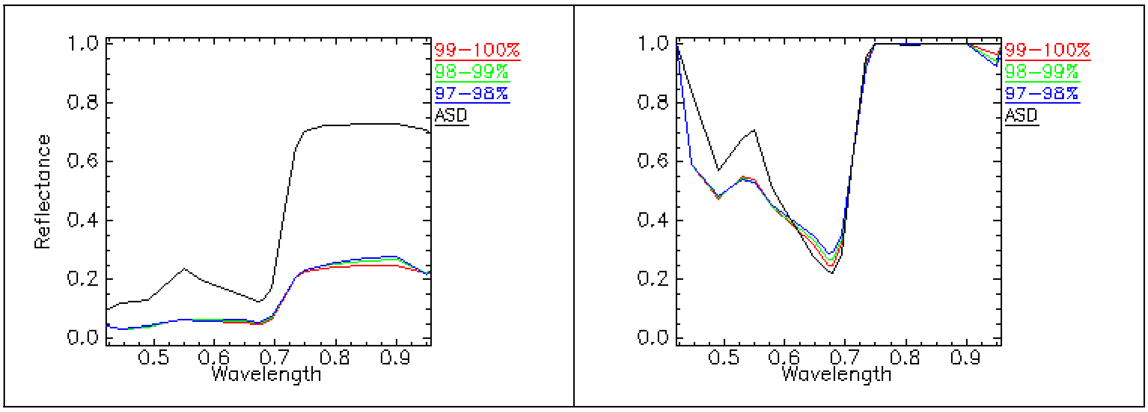

Figure 10. ***Melaleuca*** **SAM results 97-100% top threshold plotted against ASD spectra. Reflectance and continuum removed.**

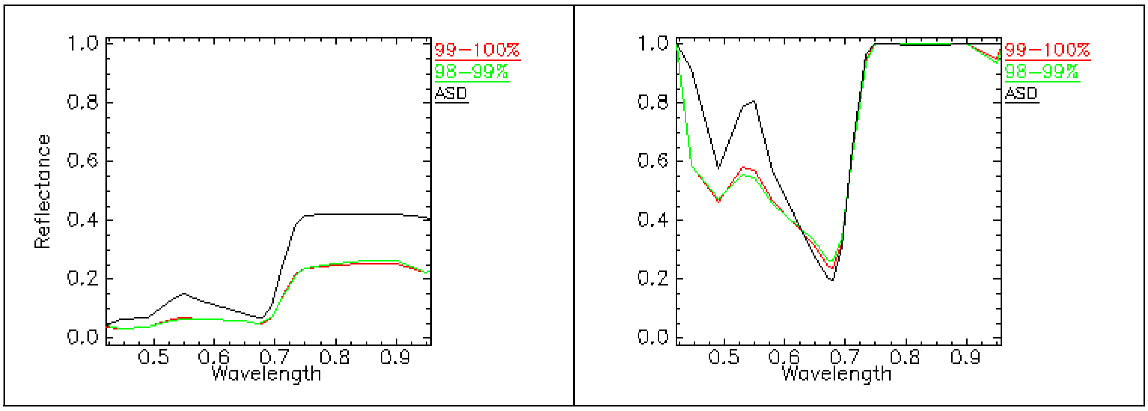

Figure 11. ***Urochloa*** **(green) SAM results 98-100% top threshold plotted against ASD spectra. Reflectance and continuum removed.**

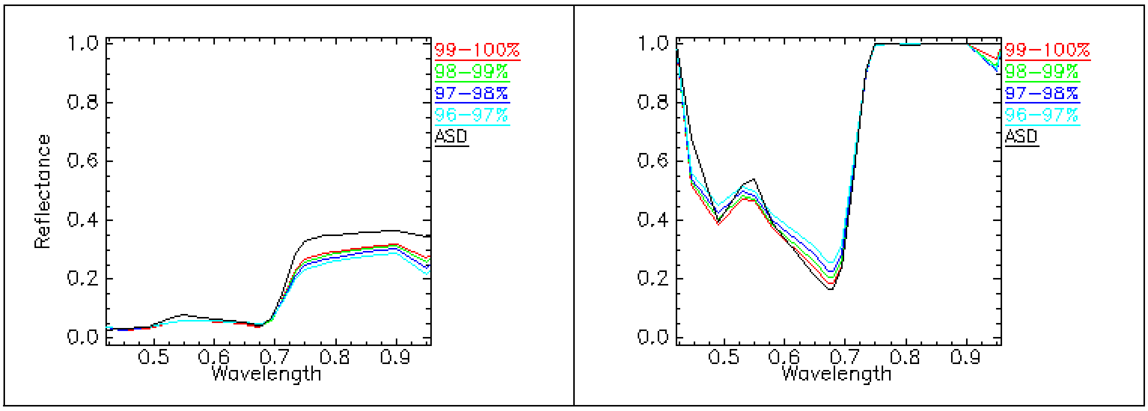

Figure 12. ***Acacia*** **leaves SAM results 96-100% top threshold plotted against ASD spectra. Reflectance and continuum removed.**

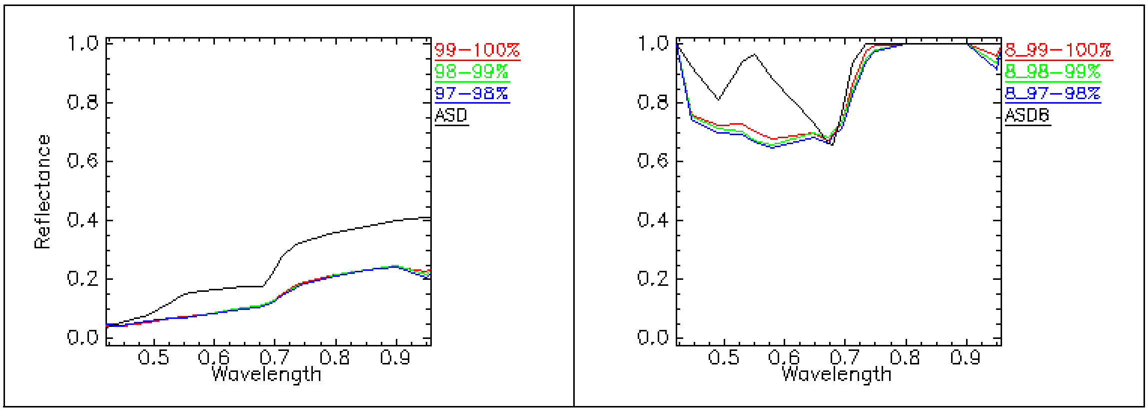

Figure 13. ***Urochloa*** **(drying) SAM results 97-100% top threshold plotted against ASD spectra. Reflectance and continuum removed.**

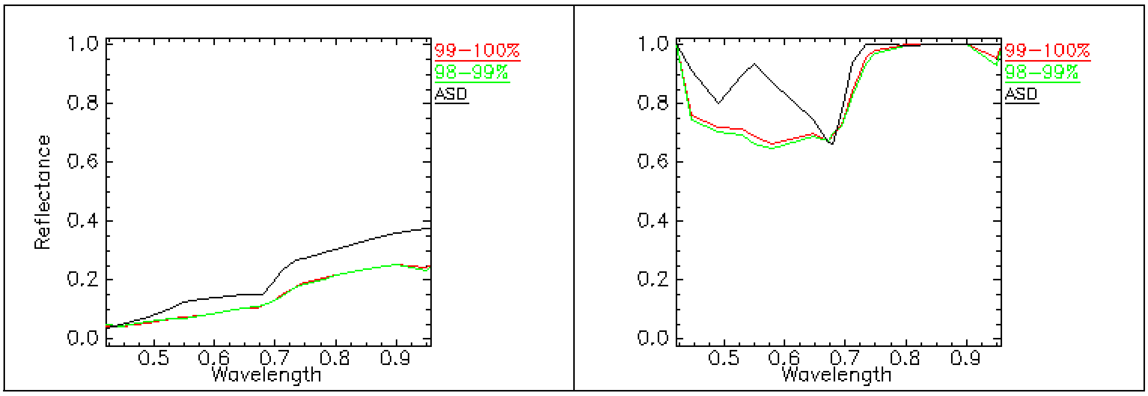

Figure 14. ***Pseudoraphis*** **SAM results 98-100% top threshold plotted against ASD spectra. Reflectance and continuum removed.**

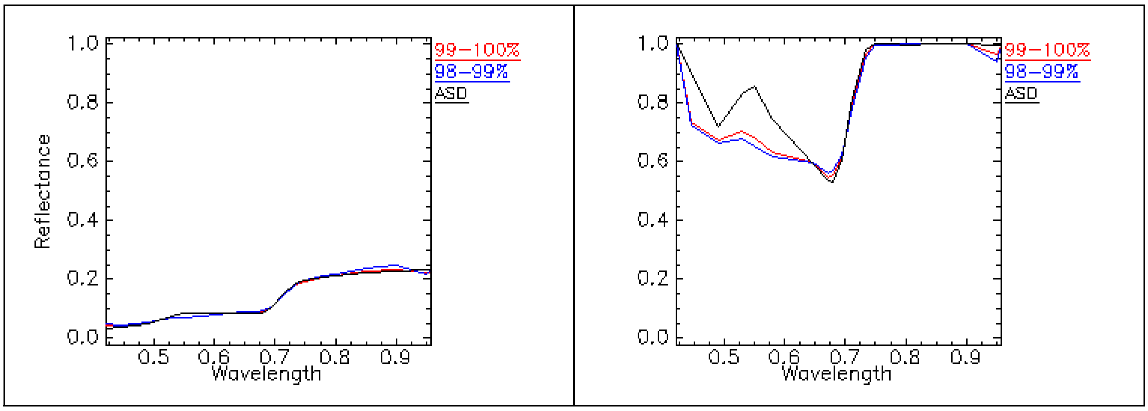

Figure 15. Green grass SAM results 98-100% top threshold plotted against ASD spectra. Reflectance and continuum removed.

Discussion

Field-based spectral measurements of land cover features, including dominant native and introduced plant species, were acquired at Nabarlek. However, due to time constraints not all vegetation species or land cover components of the study area were characterised. Additionally, the method of collecting vegetation spectra varied; for example, with respect to grasses a vertical spectrum was made, and for trees (*Acacia* sp. and *Melaleuca sp.*) only leaf spectra were acquired. Despite the limited number of spectra measured, it was useful to gain understanding of the reflectance and continuum removed profiles for potential separability of a range of vegetation types.

At the time of field spectral collection, native *Heteropogon* sp. and the invasive weed *A. americana* were senescent and brown in colour. *Urochloa sp.* and *Pseudoraphis* sp. were senescing and turning yellow in colour. In contrast, *Acacia* sp. and *Melaleuca* sp. leaves were green. The ground-based spectra for the dry, green, and yellowish vegetation appeared separable based on the positioning of absorption features. Species within these vegetation groups showed potential separability based on differences in their reflectance magnitude.

There was a delay between image capture and field-based spectra as a result of site inaccessibility. Although individual ground cover plant species could not be separated using CASI data, dried, green and yellowing vegetation groups were. The highest percentile threshold of the SAM results showed that similar CASI spectra were obtained for *Heteropogon* sp. and *A. americana*, *Acacia sp.* and *Melaleuca* sp., and, *Pseudraphis* sp. and *Urochloa* sp.. In addition, ground-based knowledge and visual inspections suggested spatial overlap of the species within these groups, particularly at lower thresholds.

Dried grasses were seperable from other vegetation types in the visual analysis of the field spectra and the SAM CASI image spectral results.A marked difference in the abundance of dried grass on the minesite compared with the surrounding landscape was observed at the time of image capture; on the minesite dried grasses were observed to be less abundant, with the exception of a few minor sites (the southern and western areas from the waste rock dump and mine pit, and along the edges of tracks). This difference may reflect the effects of recent fires on vegetation at the Nabarlek site, rather than major differences in communities with the surrounding landscape. A sharp boundary was obvious to the east and south of the minesite fence, where dried grasses appear to be a natural feature of the vegetation. Hence, the CASI data showed that the vegetation of the Nabarlek minesite had been affected by recent fire and illustrates these fine-scale effects. Visually, there were marked differences between the minesite and surrounding vegetation cover. In particular, the CASI data showed sparse patterns of vegetation cover on the old mine pit, waste rock dump, evaporation ponds, stockpile runoff pond and ore stockpile. The dense grass cover associated with the moist area of the plant runoff pond were an exception.

The spectra of green vegetation generally corresponded to tree canopies rather than other green vegetation such as green grasses. Dense patches of tree canopies were mapped outside the mining site, including woodland areas, escarpment and riparian trees. Less tree cover was observed on the minesite, although *Melaleuca* areas to the west of the evaporation ponds and trees around the plant area were mapped. Yellowing vegetation was mapped on the minesite in areas such as the perimeter of the plant runoff pond and to the south of the waste rock dump and runoff pond. These areas are moist and contain *Pseudoraphis* (a wetland grass). No matches were found for the top threshold of the class of mixed grasses (*Brachiaria* and *Hyptis*).

Although spectral signatures of all land cover features were not characterised, the results show that CASI data are useful for discrimination of broad vegetation communities. The SAM results show also that ASD signatures correspond well to the CASI thresholds mapped for the green and dried vegetation. However, despite good agreement between image thresholds and ASD spectra for these individual species, due to spectral similarity and ground resolution, individual species described in this paper were inseparable.

Visual examination has shown that the above method has not used all image data information (image purest pixels). In addition, at the time of image capture, *Acacia* trees present on the minesite were flowering. Visually, *Acacia* trees appear separable from other trees because of the spectral contribution from their yellow flowers. Image based mapping will therefore be implemented.

Conclusions & Future work

The full wavelength ASD spectra showed good separability between vegetation types. Resampling these to CASI wavelengths showed that CASI data should distinguish between green, dried and yellowing vegetation. Based upon the ASD spectral measurements of leaves and not full canopies, separability of tree species would not be achieved.

CASI data showed that the vegetation abundance (and composition in the case of *Acacia*) of the minesite area differs from the surrounding non-mined landscape. Discriminating between dry and green grasses, and trees, allows the minesite to be characterised in order to assess the success of rehabilitation. In contrast to conventional ground-based point sampling methods, CASI information provides a complete “picture” of the minesite and surrounding landscapes from a single date capture.

Future work will include an analysis of image data alone (MNF, PPI nth-Dimensional Visualisation and mapping). More thorough vegetation spectra characterisation are needed, including spectral signatures encompassing a range of reflectance contrast related to phenological changes and vegetation component spectra (leaves, flowers, background soil). Information on spectral changes with seasonality will provide necessary insight into optimal timing of image capture for the discrimination of priority land cover features from remotely sensed CASI data.

Comprehensive ground-based transect sampling measuring woody plant density and herbaceous cover has been implemented. Once complete, this information will contribute to accuracy assessments. This current work is part of an assessment of the use of remote sensing for minesite rehabilitation assessment at Nabarlek. The infrequency of airborne optical missions in the Top End of the Northern Territory makes the assessment of remotely sensed data for minesite characterisation challenging and may be a constraint until cost-effective compared to other methods. Both the CASI in the current study, and HyMap data captured over the site in September 2002, were opportunistic and experimental.

Ideally, for minesite rehabilitation assessment, remotely sensed data coupled with ground-based sampling is performed at designated time frames. Climatic conditions and associated responses of vegetation at the Nabarlek minesite indicate that the late dry season is useful to distinguish between annual and perennial covers, as well as some tree species that are flowering. The late wet – early dry season timeframe provides information on waterlogged soils and their effects on revegetation. Without reliable temporal coverage of airborne platforms, future work will focus on Quickbird satellite data that will be captured at the time of transect field-based sampling (late dry and late wet seasons). A cost effective benefit comparison with a variety of remotely sensed data and field-based techniques will then be performed.

Acknowledgments

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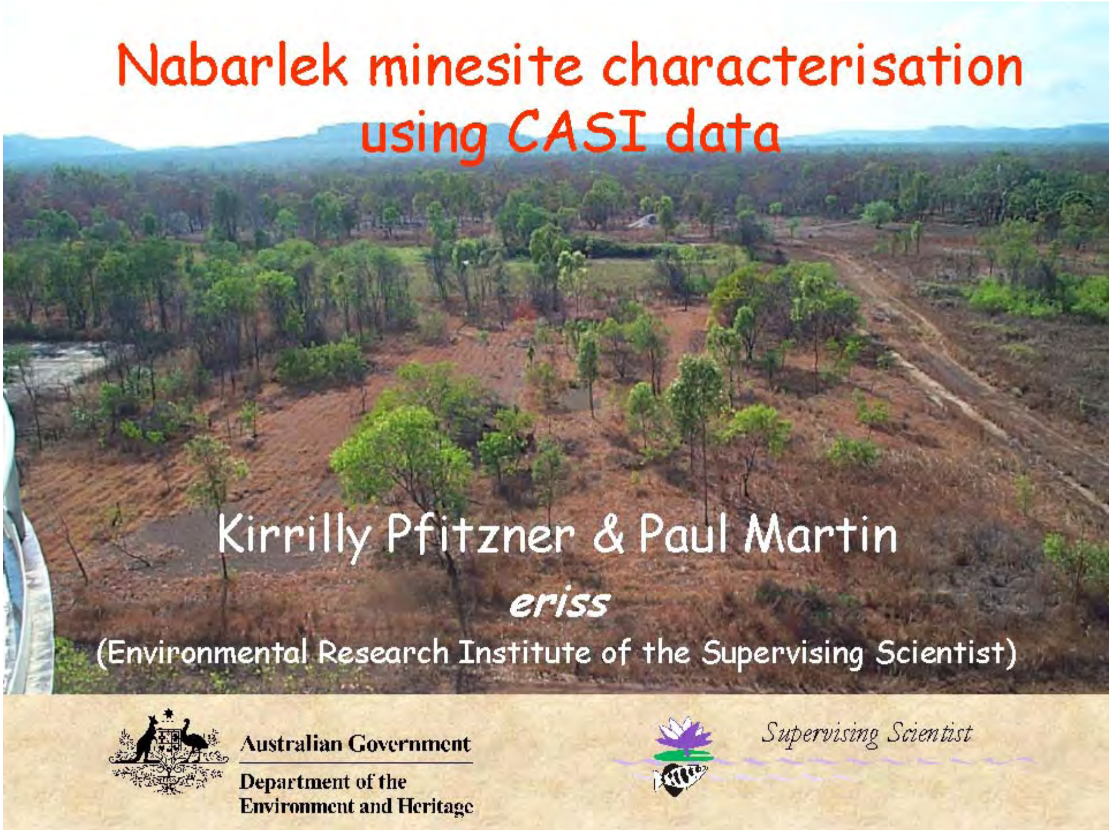


Methods for minesite rehabilitation assessment

No quantitative industry standard for revegetation.

Examples of methods include:

- Point based field checks
- "Traditional" ecological based fieldwork
- Ecosystem Function Analysis (EFA)
- Remote Sensing

Australian Government
Department of the Environment and Heritage

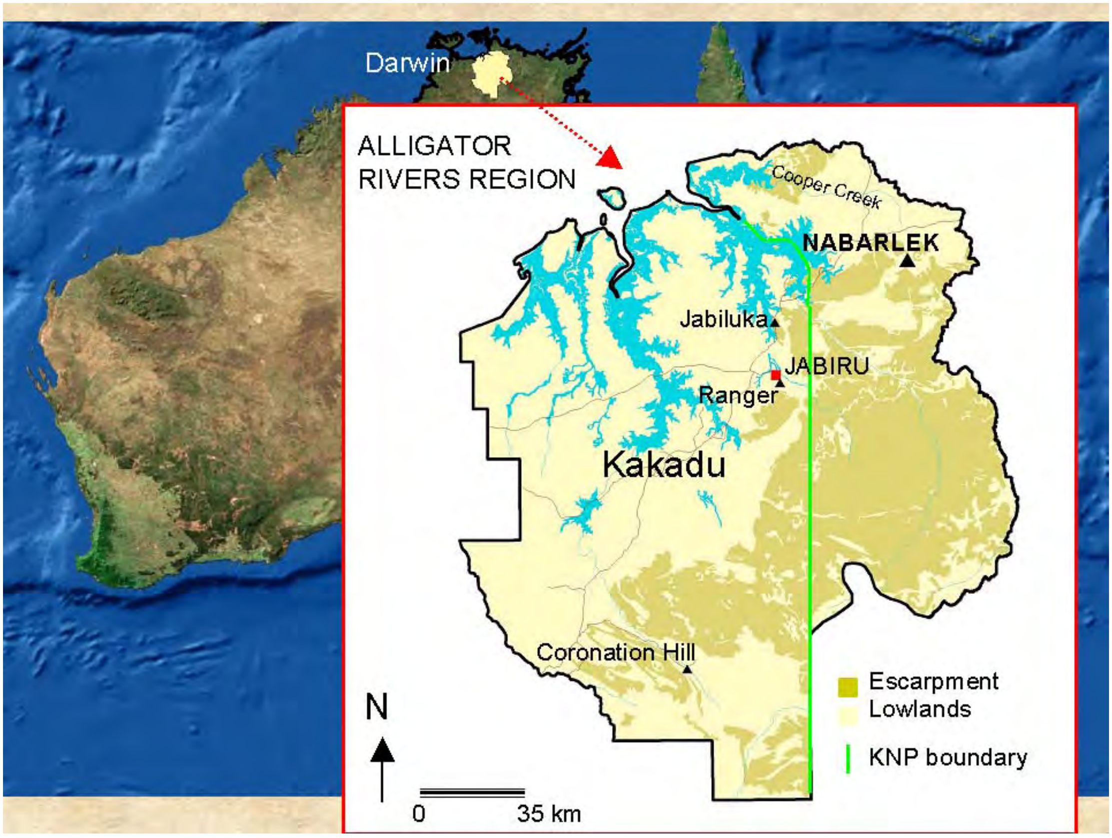
Supervising Scientist

Project aims

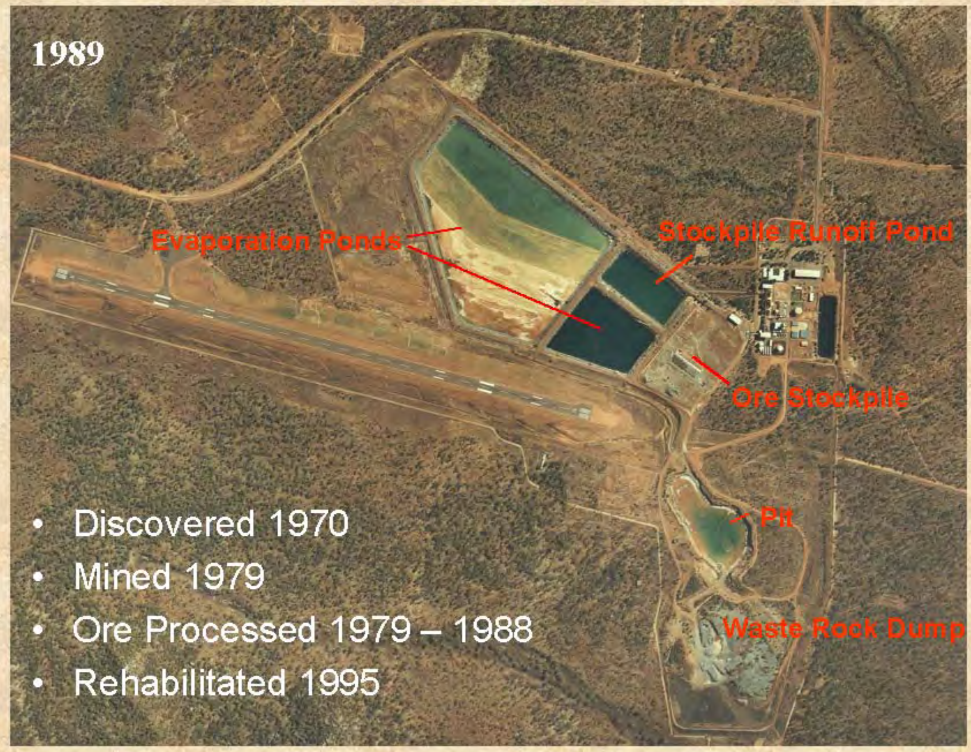
- Assess whether vegetation on the minesite blended with surrounding vegetation
- Contribute to a quantitative description of the minesite vegetation
- Develop cost-effective remote sensing and field-based method for minesite assessment

Australian Government
Department of the Environment and Heritage

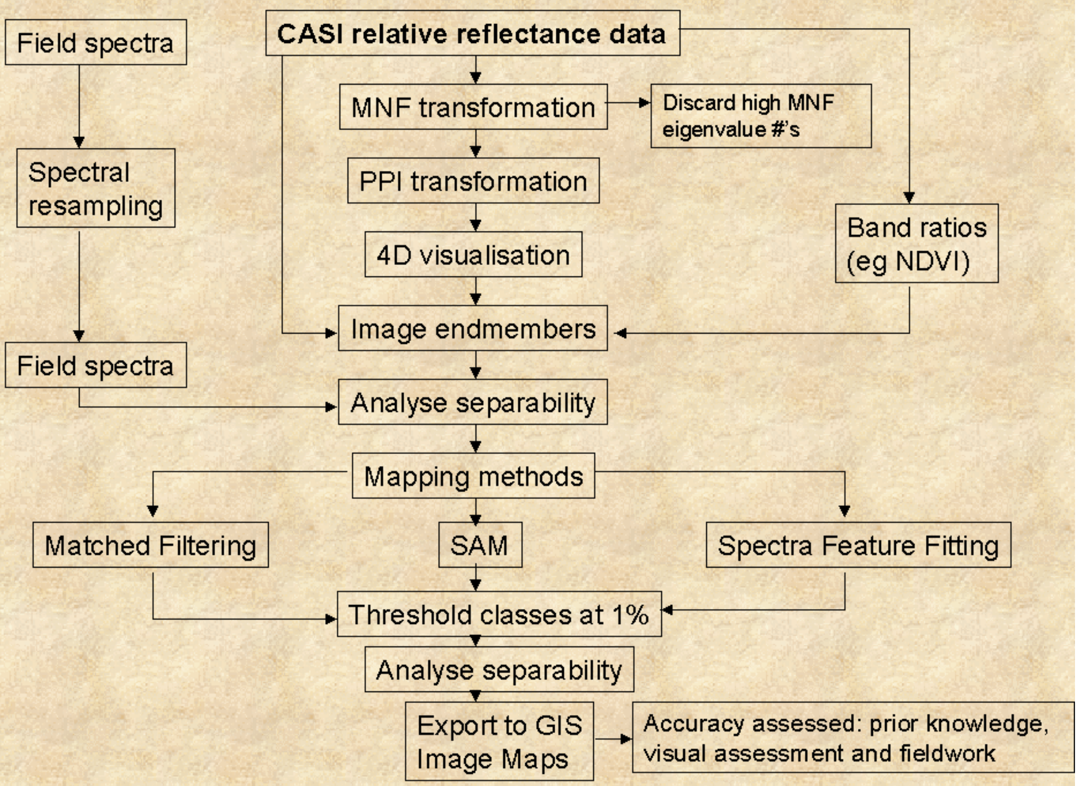
Supervising Scientist

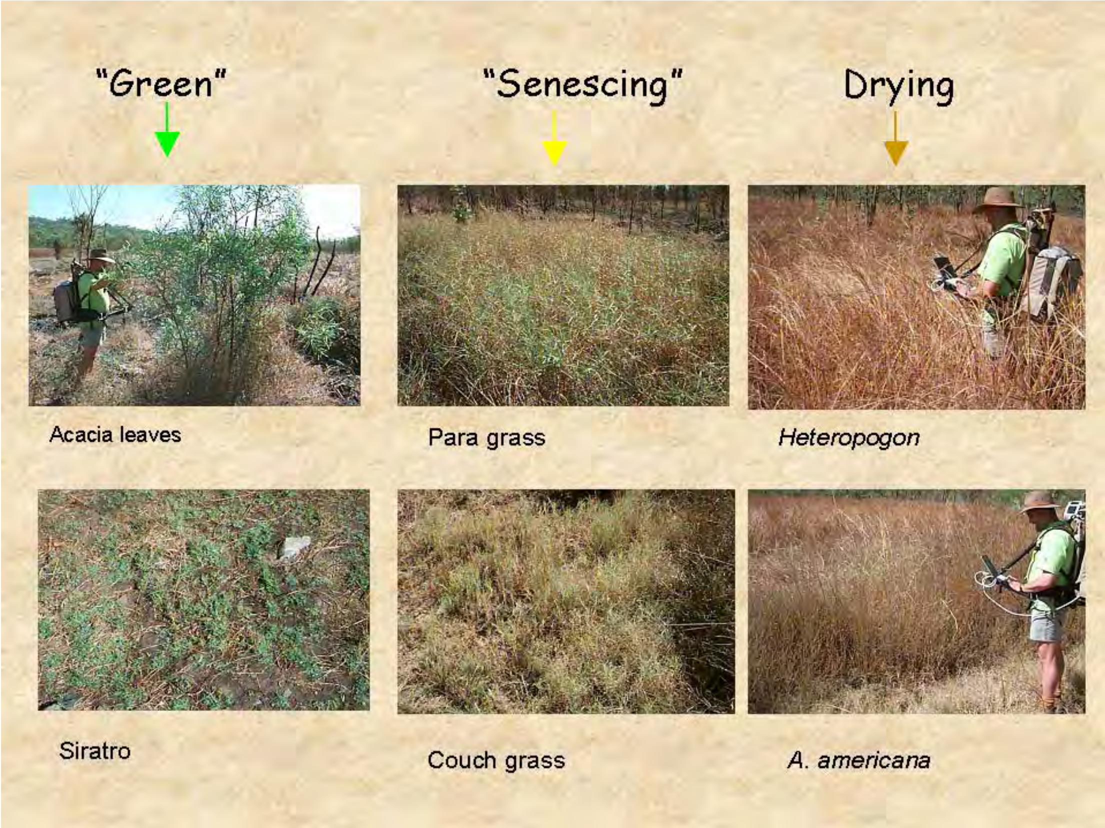


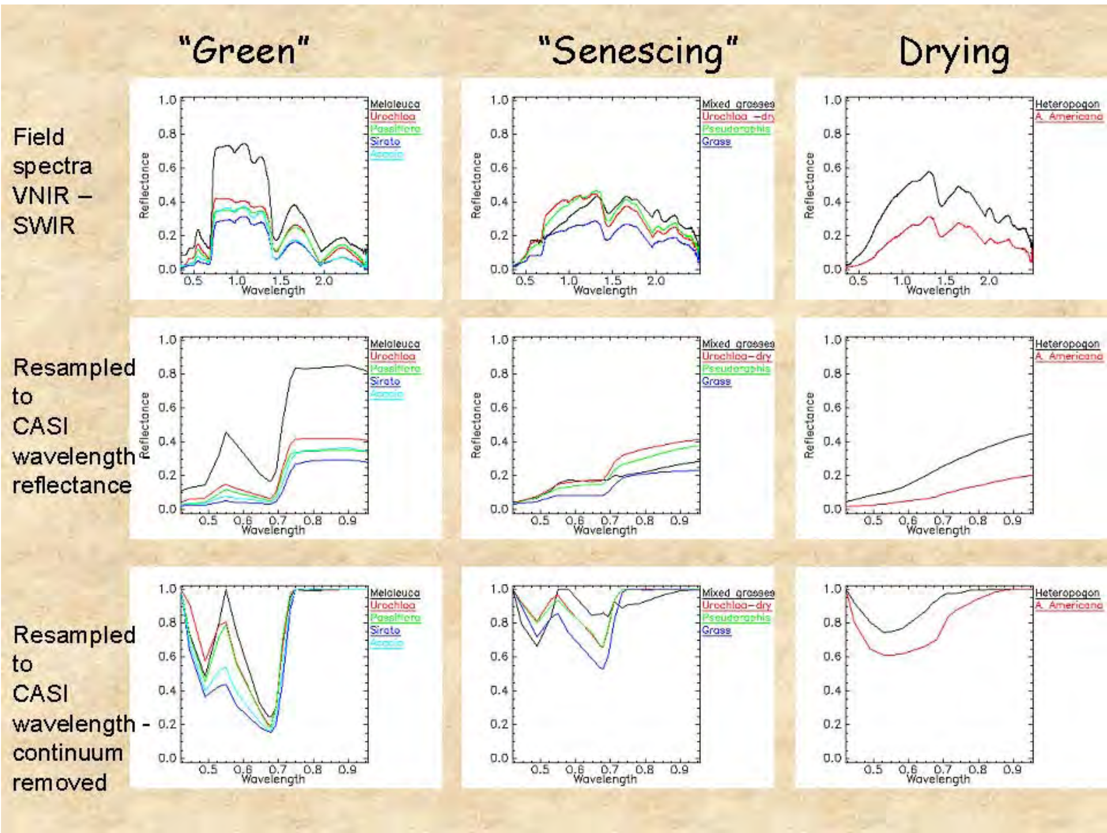
Nabarlek minesite

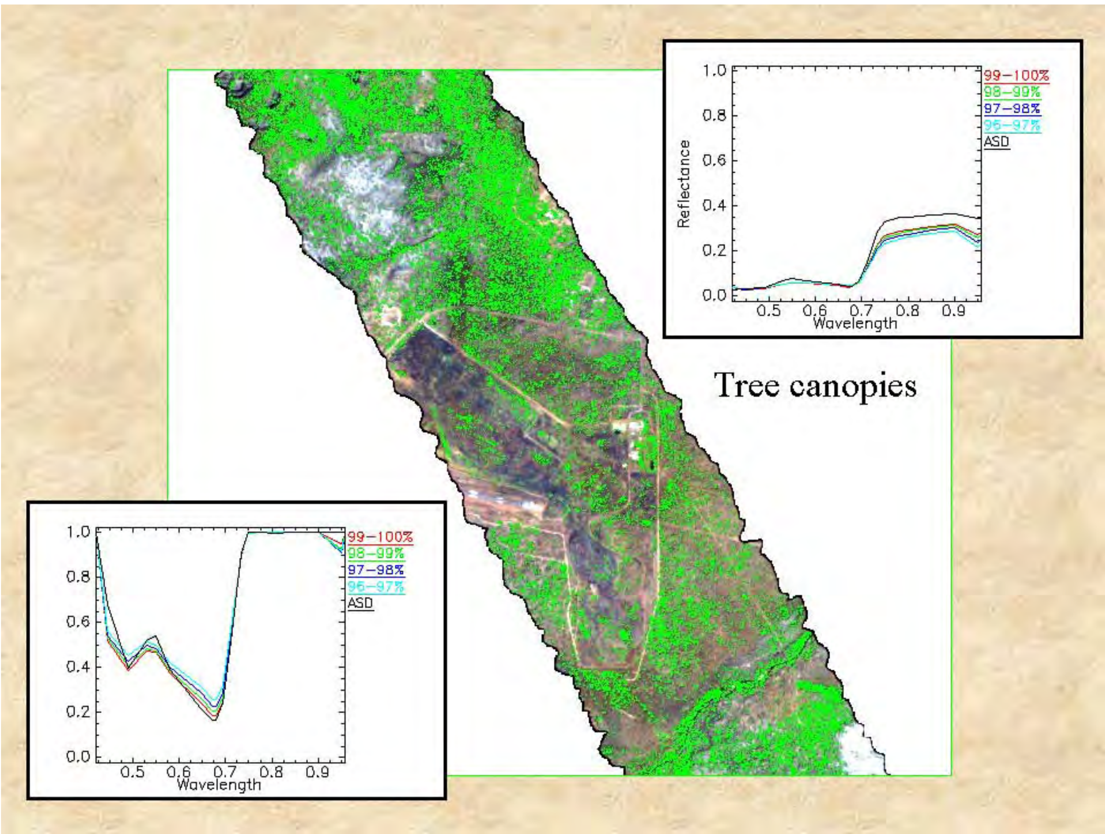


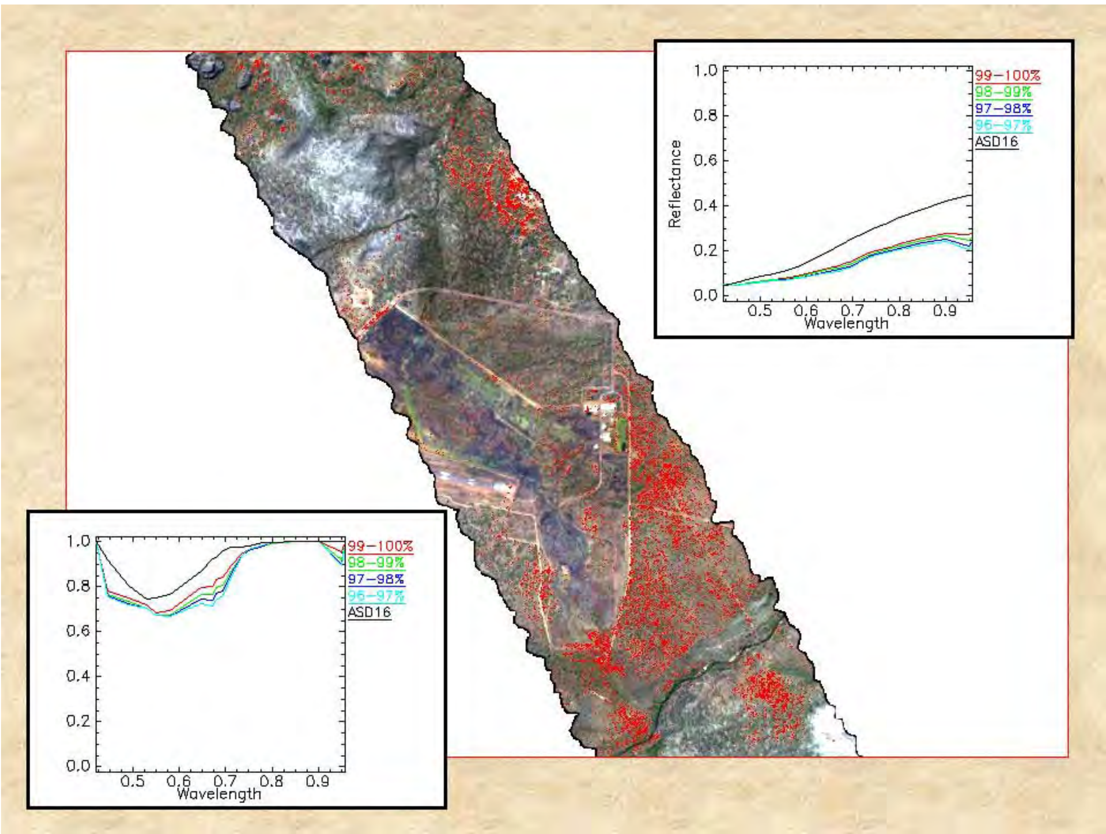
- Discovered 1970
- Mined 1979
- Ore Processed 1979 – 1988
- Rehabilitated 1995

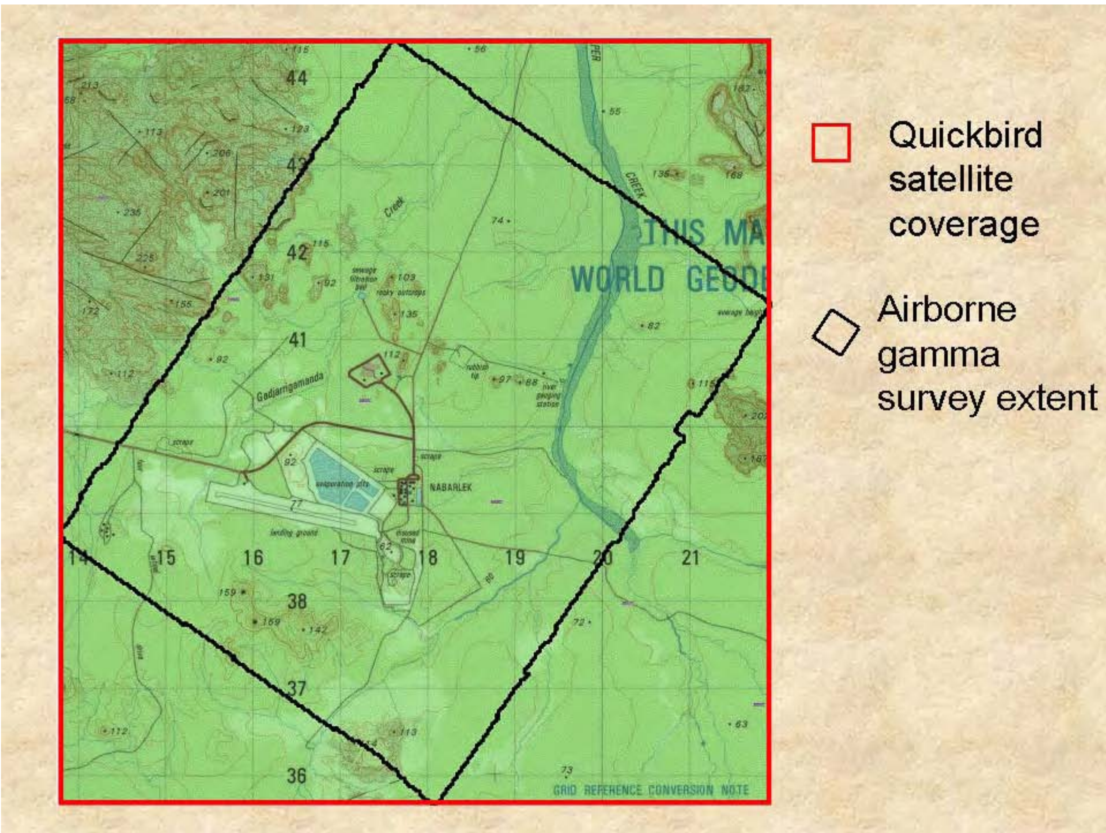


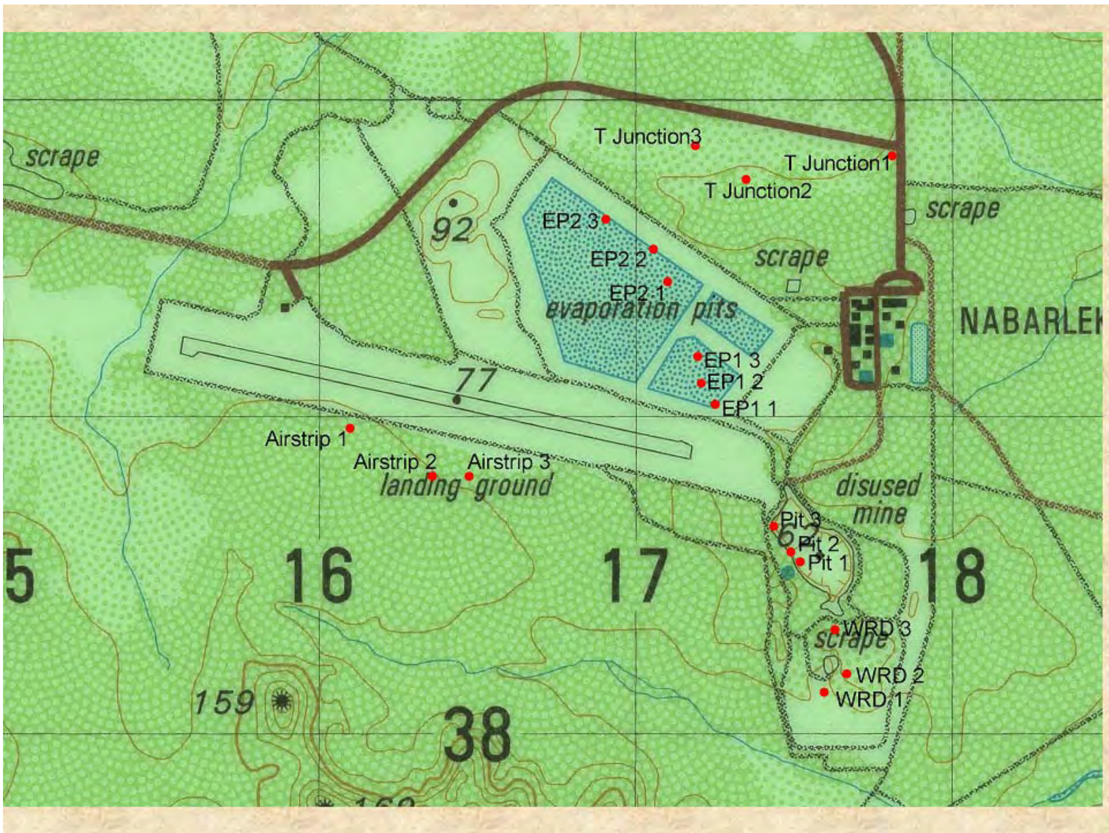

"Green"
"Senescing"
Drying
Acacia leaves
Para grass
Heteropogon
Siratro
Couch grass
A. americana


"Green"
"Senescing"
Drying
Field spectra VNIR – SWIR
Resampled to CASI wavelength reflectance
Resampled to CASI wavelength - continuum removed
Reflectance
Wavelength
Melaleuca
Urochloa
Siratro
Acacia
Mixed grasses
Pseudoraphis
Grass
Heteropogon
A. Americana

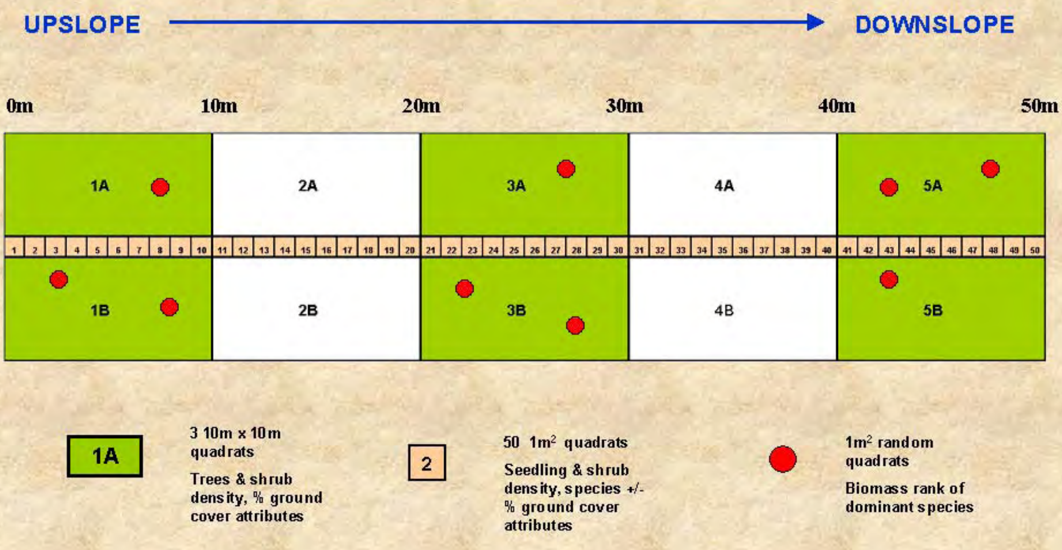

1.0
0.8
0.6
0.4
0.2
0.0
Reflectance
0.5 0.6 0.7 0.8 0.9
Wavelength
99–100%
98–99%
97–98%
96–97%
ASD
Tree canopies
1.0
0.8
0.6
0.4
0.2
0.0
0.5 0.6 0.7 0.8 0.9
Wavelength
99–100%
98–99%
97–98%
96–97%
ASD


1.0
0.8
0.6
0.4
0.2
0.0
Reflectance
0.5 0.6 0.7 0.8 0.9
Wavelength
99–100%
98–99%
97–98%
96–97%
ASD16
1.0
0.8
0.6
0.4
0.2
0.0
0.5 0.6 0.7 0.8 0.9
Wavelength
99–100%
98–99%
97–98%
96–97%
ASD16


Quickbird satellite coverage
Airborne gamma survey extent
NABARLEK
evaporation pits
landing ground
Gadjarrigamanda
GRID REFERENCE CONVERSION NOTE


T Junction3
T Junction1
T Junction2
EP2 3
EP2 2
EP2 1
EP1 3
EP1 2
EP1 1
Airstrip 1
Airstrip 2
Airstrip 3
Pit 3
Pit 2
Pit 1
WRD 3
WRD 2
WRD 1
scrape
evaporation pits
landing ground
disused mine
NABARLEK

Transect design – Nabarlek Vegetation Surveys



Results

- Field spectra curves - differences in reflectance of vegetation;
- Not all vegetation sp. / land components spectrally characterised;
- Gained understanding of reflectance and potential separability;
- Dry, green and yellowy spectra appeared separable; species within these groups showed potential separability;
- Groups of vegetation were separable, individual sp. were not;
- CASI data useful for discriminating vegetation communities;
- Vegetation of the minesite differs from the surrounding landscape

Future revegetation assessment