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Current applications of hyperspectral remote sensing in the discrimination of Australian Eucalypt species

Laurie A. Chisholm
University of Wollongong, lauriec@uow.edu.au

B Datt
GeoQuEST Research Centre

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Keywords

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Current Applications of Hyperspectral Remote Sensing in the Discrimination of Australian Eucalypt Species

Chisholm, L.A. and Datt, B.
GeoQuEST Research Centre, School of Earth and Environmental Sciences, University of Wollongong Wollongong, NSW, 2522, Australia, Tel : +61 2 4221 3765 Fax : +61 2 4221 4250
E-mail : lauriec@uow.edu.au

Abstract

Hyperspectral remote sensing provides detail on biophysical variables related to forest ecosystem processes useful for tracking and predicting structure and function of vegetation Considerable potential of laboratory spectrometry and near-range work in the field to derive stress indicators and changes in chlorophyll content has been demonstrated that includes a range of studies conducted on unique Australian vegetation types. Although considerable advances have been made at these levels, progression to the airborne platform has been more limited and mostly applied to the detection of effects of damaging agents. There remains a need for research effort on basic applications including species identification, a significant research challenge that is just beginning. The following paper reviews the current use of hyperspectral remote sensing for the spectral discrimination of eucalypt species in Australia. Within this context, the specific nature of Australian vegetation is characterised and consideration given to algorithms and integrative technologies that contribute to success.

1. Introduction

Australia is recognized as one of only 12 biologically mega-diverse nations (Common and Norton, 1992). Thus, the conservation and management of eucalypt-dominated ecosystems is not just of regional importance, but of global significance (Commonwealth of Australia 1997). In particular, the conservation of eucalypt-dominated ecosystems is important because they support most of Australi's terrestrial biodiversity (Keast, 1981 and Kirkpatrick, 1994).

The Montreal Process prompted considerable research on the development of criteria and indicators for the sustainable management of forests at an international level, subsequently fostering research in Australia to establish baseline information on forest communities and species in order to assess future directions in sustainable forest management. Therefore, commerce and the global community are driving the push for an improvement in remote sensing as a means to provide information for sustainable forest resource and ecosystem management (Moffiet et al., 2005).

Stone and Coops (2004) cite a growing need for more detailed and accurate information related to forest inventory parameters as the forestry industry continues to mature. There is a demand for improved site selection, growth predictions, and knowledge of disturbance effects to improve management guidelines and to achieve the best possible commercial return. Most on-ground inventory assessments at the stand level are rarely sufficient for operational or short-term planning. An individual tree inventory would prove useful but is highly ambitious; first it must be determined if an individual tree based approach can be used to aggregate at the stand level and thus replace portions of the forest management inventory process (PRSE ref to find).

Remote sensing has demonstrated wide applicability to mapping forest physical and structural features (Treitz and Howarth, 1996 and 1999). Focus in recent years has been directed towards measuring the biophysical and physiological character of forest ecosystems in order to estimate and predict forest ecosystem health and sustainability.

Major advances are being made in Australia and overseas in the acquisition and interpretation of hyperspectral remote sensing data related to forest inventory parameters, in particular, leaf area, canopy structure and canopy function (Datt 1998, 1999a, 1999b, Stone et al., 2000, Stone et al., 2001and Mohammed et al., 1997. With the advent of airborne hyperspectral systems as well as high spatial resolution systems, and combinations thereof, a natural progression to species discrimination is occurring. There is a distinct need to demonstrate the potential of using hyperspectral data and integrated spatial technologies to identify individual species.

This paper focuses on the current status of hyperspectral remote sensing for discrimination of eucalypt species. In doing so, it also reviews the unique foliar characteristics of Eucalypts, and addresses more generic issues of data integration, physical models, and confounding factors, making it applicable to the broader plant science community.

2. Eucalypt foliar characteristics

Australian ecosystems are highly variable and differ significantly from their counterparts in Europe and North America (Fitzpatrick and Nix, 1970). The Eucalypts are an evergreen woody plant with many species in the genus that differ in physiology according to environment (Williams and Brooker, 1997) with water availability being a major determinant of plant growth. Savannas cover ~ 25% of the northern part of Australia (Eamus et al., 2000) and are greatly affected by disturbance, while in contrast the temperate eucalypt forests in high rainfall areas can be highly productive and economically valuable, even though they cover only 1% of the continent (Leuning et al., 2005). A striking feature of forests and woodlands dominated by species of Eucalyptus is the high proportion of overhead light penetrating the canopy as compared to other forests of similar stature, for example, plantations of Pinus radiata (King, 1997). This high light penetration is due to steeply inclined foliage and a rather low ratio of leaf area to ground area, ranging from 1 to > 3 in tall eucalypt forests (King, 1997). Thus mature evergreen eucalypts tend to have sparse crowns with pendulous leaves (James and Bell, 1995) and a wide range of leaf growth from juvenile to mature can be found on a single branch (Lees and Ritman, 1991). The majority of species consist of a petiolate leaf, which is lanceolate or ovate in shape, with the colour and venation being similar on both sides of the leaf (isobilateral). Patterns of leaf inclination in eucalypts are clearly related to environment and growth, with most species having pendulous, nearly vertical leaves to reduce midday heat loads, thereby increasing water use efficiency and carbon gain (Cowan, 1981 and King, 1997). As noted by Bell and Williams (1997) this adaptation enables eucalypts to evade high temperatures at the leaf surface, and therefore avoid excessive transpiration rates. These features, in combination with the development of deep roots and lignotubers (Florence, 1981) increase drought resistance and allow eucalypts to extend over regions of a wide range of water availability.

A waxy glaucescence is characteristic of the leaves of a number of Eucalyptus species (Greaves and Spencer, 1993) providing considerable protection of the leaf surface against insect attack. The wax crystals covering the surface of leaves act as diffuse reflectors of light, and effectively reflect the radiation incident on a leaf (Thomas and Barber, 1974). As a result the proportion of total available photo-synthetically active radiation (PAR) absorbed is reduced (James and Bell, 1995). The glaucous covering on the leaves of certain eucalyptus species may allow the leaves of these plants to be exposed to greater levels of radiation without damage to the photosynthetic apparatus (Greaves and Spencer, 1993). Conversely, the waxy covering of the leaves may necessitate the greater interception of light for adequate photosynthesis to take place. Thus the unique waxy leaf covering and leaf orientation affect the amount of direct radiation received and hence may affect the potential for leaves to become photoinhibited. Lewis et al., (2001) suggest there may be diagnostic absorption features related to the high content of volatile aromatic oils or waxy cuticle in Eucalyptus leaves, which may prove to be diagnostic of some species.

The production of carotenoid pigments in new leaves is another mechanism that has been associated with protection from photoinhibition (Nobel et al., 1991). These physiological adaptations at the leaf level have developed to serve as protective mechanisms and distinguish eucalypts from other species, particularly those from the northern hemisphere. Anthocyanin leaf pigments cause a red or purple discoloration of eucalypt leaves often attributed to stress processes, which has been shown to affect spectral reflectance (Stone et al., 2001).

Patterns of shoot extension and refoliation of eucalypts differ from many of the commercially-important tree genera in the temperate Northern Hemisphere (Landsberg and Gower, 1997). Eucalypts have a very opportunistic leafing phenology, although rapid leaf expansion usually occurs in moderately synchronised seasonal flushes (Stone, 1999). Another distinctive feature of the eucalypts is their well-developed ability to produce regrowth foliage from dormant buds that develop into epicormic shoots (Landsberg and Gower, 1997). Stressed eucalypts are therefore able to present a façade of dense green epicormic growth. A further complication is the difficulty of discrimination between young eucalypt foliage with a red colouration typical of many healthy eucalypt species (Brooker and Kleinig, 1990), and mature foliage with a reddish discolouration often associated with stress or damage (e.g. Wall and Keane, 1984, Stone et al., 2001).

In addition, for an open canopy the incoming radiation interacts not only with the vegetation canopy, but also, depending on the actual amount of cover, with the soil background (Kumar et al., 2002). At the crown scale there can be a reduction in crown biomass due to defoliation and crown contraction if condition is poor (Stone et al., 2000, 2001). Therefore, studies intending to spectrally discriminate between species must also address the cumulative effect of canopy cover and soil/litter background.

3. Background

Considerable experimentation in the discrimination of forest communities and/or species remains yet to be done. The literature shows a large number of studies on the topic outside Australia (Treitz and Howarth, 1999), with far fewer studies conducted within. Most Australian studies to date have been highly variable across communities, species, and location and exacerbated by the inherently different structure and composition to northern hemisphere vegetation as summarised above, the need for systematic Australian studies is well seen.

There are a growing number of international studies that include the identification of species composition (Franklin et al., 2001; Key et al., 2001), estimation of individual tree species and crown closure (Cohen et al., 1995, 2001; Gerylo et al., 1998) with varying levels of success (Wulder et al., 2004). The advent of high spatial resolution data fostered the development of algorithms that automate the delineation of tree crowns has continued since the mid-1990ís (Gougeon, 1995).

The increasing availability of high spatial resolution (<1m/pixel) imagery from satellites such as IKONOS is assisting this shift from a pixel-based approach towards one of the detection, delineation and classification of the individual tree (PERS, 2004 or 2005 ñ check). While meeting forest inventory needs, such information also better meets the need for resource management related to biodiversity and sustainability.

At the same time, other types of sensor technology are rapidly advancing (McGraw et al 1998), including developments in active systems such as LIDAR. Integration of measurements from such instruments with reflectance imagery is already being shown to greatly enhance the ability to detect the spectral subtleties that facilitate species discrimination (Lucas if in press).

However, studies to address species discrimination are usually conducted over relatively small geographic areas, usually due to high operational costs and the tedious requirements of image processing. In addition, hyperspectral sensors are not as readily available in Australia as the USA or Europe.

4. Identification of Individual Species

To date few studies have been published specifically aimed at the discrimination of eucalypt species in Australia using hyperspectral data. However, there are several others in submission, in press or in progress, with others located within conference proceedings that are not reviewed here. There is also a body of work that has included species identification as part of a larger study on vegetation health (Stone et al., 2001, 2004, 2005; Goodwin et al., 2005a), on exotics (Goodwin et al., 2005b) or in the use of alternative sensors (eg LIDAR) to facilitate identification (Moffiet et al., 2005). More broadly, several studies have attempted discrimination at the community or ecosystem level (Lewis et al., 2001 and Held et al., 2003) with relevance to eucalypt species identification.

The most commonly used techniques for extracting and mapping vegetation from hyperspectral imagery include variants of linear mixture analysis, and wavelength-specific techniques such as narrow-band ratios and spectral absorption feature matching (Lewis et al., 2001). In particular, Lewis (2000) found success in differentiating Eucalyptus from other tree species using automated mixture analysis of hyperspectral imagery. Depending on sensor resolution, often data have been aggregated to the community level for success.

However, a number of crown delineation algorithms have been developed using methods that detect crown centroids (through local maxima) and boundaries (Culvenor, 2000 and 2002), utilize contour-based approaches (Gougeon, 1995 and Leckie et al., 2005), or rely on template matching (Pollock, 1996; 1999). Most algorithms are limited to determining crown maxima with difficulty in distinguishing between overlapping crowns, in dividual species, or having success in low density canopies (Mei and Durrieu, 2004).

Coops et al., (2004) and Goodwin et al., (2005a) have demonstrated that significant spectral differences can occur between eucalypt tree species using hyperspectral data, crown delineation methods, and statistical techniques. Both studies demonstrated limited success in spectral differentiation at the canopy scale. Using a dataset of 10 narrow bands, Coops et al., (2004) manually delineated tree crowns of varying condition to extract crown spectra from CASI-2 imagery. ANOVA results isolated species-specific reflectance where some discrimination between eucalypt species was found, with 720 and 740nm wavelengths providing the best discrimination. However, there were species where discrimination was not possible, and in general, it was found that eucalypts remain difficult to spectrally discriminate from one another. Similarly, Goodwin et al., (2005a) investigated the use of CASI 2 data for classifying eucalypt species, finding success in discriminating a single non-eucalypt species, but also had difficulty discriminating one eucalypt species from another with only one out of six eucalypt species being particularly distinguishable. Useful wavelengths for discrimination between species varied between the two studies suggesting the difficulty of discrimination between individual eucalypt species where methods of crown sampling differ. Results demonstrate that delineation algorithms still have difficulty with determining crown maxima, with research needed to investigate ways to overcome difficulties with overlapping crowns, shadow effects, and low vs high density canopies. The difficulties of discriminating between eucalypt species, with open crowns, confounding soil backgrounds, and pendulous leaves remains challenging.

The difficulty in delineating crowns in more complex mixed species forests using established algorithms has motivated the development of a tree crown delineation algorithm within eCognition (Bunting and Lucas, 2005), using an object-orientated approach which will likely provide improved success for the many problems encountered using delineation algorithms to date, eg: reducing segmentation within expansive crowns; isolation of crown gaps, incorporation of isolated trees with similar crowns; and differentiation of understorey and/or dense forest..

5. Confounding factors attributing to variability

Even within what is usually described as a single biome, habitat complexity and community patterns can vary enormously to the degree that structurally diverse components of vegetation such as the dominant canopy of Eucalyptus, and associated sclerophyllous understorey can vary considerably (Lassau et al., 2005). In addition, a forest may consist of several vegetation communities characterised by the dominance of different tree species and understorey (Menges et al., 2001). Individual trees are an aggregation of leaves/needles, branches and stem, each of which becomes dominant at a different scale of observation.

Leaf optical properties are influenced by the concentration of chlorophyll and other biochemicals, water content, and leaf structure (Datt 1999 and Kumar et al., 2001). All of these leaf characteristics are highly variable and further affect the reflectance of vegetation during the complex changing process within the leaves, the canopy and the stand (Kumar et al.,2001) during growth, maturity and senescence (Roberts et al., 1998, Stone et al., 2005), and stress (Stone et al., 2001, 2003, 2005). Longevity of the foliage has a potential impact on spectral behaviour (Stone et al ., 2005), and in the case of evergreen trees where foliage may be retained for more than 1 year (Prior et al., 1997), during which multiple stressors are likely to occur in many environments. Different plants and even different leaves from the same plant are known to be characterised by different efficiency of photosynthesis and plant growth (Buschmann and Nagel, 1993).

Separating between a range of Eucalpytus and rainforest species remains difficult (Coops et al., 2004), largely attributed to structural complexity at the stand and crown levels. Within and between crown variations provide a complicated architecture that lessens discriminatory success. In addition, unhealthy trees with thin crowns and increased canopy gaps yield a higher shadowing both within and between crowns (Goodwin et al., 2005b).

Openings in the forest canopy or vegetation cover have been identified as contributing to variability in the amplitude measurements of lidar (Moffiet et al., 2005). The ability to extract more information from intensity returns via small footprint scanning lidar holds promise to further species identification (Lim et al., 2003). Moffiet et al., 2005 have since demonstrated that small footprint scanning lidar has considerable species discrimination ability, but difficulties are still encountered with variation in lidar hit density within a mix of species, spatial variability in the vertical vegetation structure, and variation in data registration. Success of species identification with lidar is therefore subject to the degree to which the lidar footprint intercepts individual tree crowns at a single elevation (Moffiet et al., 2005), suggesting that success will vary by intensity variation, the overall forest structure (canopy closure/vegetation height), and the canopy architecture (crown gap closure). Other studies have also identified that species discrimination requires not only intensity returns at a sufficient resolution, but input from other variables including tree height, for more automated analysis (Schreier et al., 1985 and Torma, 2000), and preferably crown segmentation (Torma, 2000) that allows crown spectra to be extracted and analysed.

Adequate preprocessing of airborne hyperspectral data is critical to remove systematic and random noise (Datt et al., 2003). Numerous studies cite the sufficient level of corrections as a possible impediment to discrimination.

6. Use of physical models

Most studies on forest species discrimination have used statistical approaches such as image classification, spectral matching, spectral unmixing, and vegetation indices. While these approaches may work in some specific situations, they are empirical in nature and lack the physical basis for the method to be used operationally. Inversion of statistical models reveals only part of the canopy level information and while they may be of some use in simple homogeneous canopies such as crops and pastures, they are not suitable over complex forest canopies. Individual plant species do not have unique spectral signatures like those of minerals and rocks. Therefore canopy reflectance on its own is not a suitable variable for distinguishing species. However, the detailed spectral reflectance measured by hyperspectral sensors enables one to derive variables such as leaf biochemistry, canopy structure, texture , LAI , etc. which could be used to separate species. The spectral signature of a plant canopy is the combined effect of leaf optical properties, canopy structure, understorey reflectance, soil and litter background reflectance, and the illumination and viewing geometries. Techniques which can decompose the canopy reflectance into its various components would provide the detailed information required to identify species from their canopy reflectance. Radiative transfer models provide such a physical basis to understand the complex nature of plant canopy reflectance, and to derive detailed information about the canopy structure and leaf biochemistry. Radiative transfer models have been used with remote sensing data for many years. The three main types of radiative transfer models are atmospheric radiative transfer models, canopy radiative transfer models, and leaf radiative transfer models.

Atmospheric radiative transfer models are used to perform atmospheric correction to remotely sensed data in order to derive surface reflectance. This is an important step in the data processing stream because accurate surface reflectance retrieval is required for applications such as species identification. The reflectance data should accurately represent the surface materials and be free of artefacts caused by atmospheric scattering and absorptions. Recent advances in atmospheric correction techniques have led to the development of a number of state-of-the-art software packages such as MODTRAN (Berk et al., 1998), ACORN (AIG, 2001), FLAASH (Cooley et al., 2002), and HATCH (Goetz et al., 2003). These atmospheric correction packages are especially suited for hyperspectral data where several atmospheric parameters such as water vapour amount, aerosol amount, cloud areas, etc. are derived from the data itself, requiring little input from the user. With no requirements for ground validation data or site meteorological data in the atmospheric correction process, many airborne (and satellite) data providers are now able to provide atmospherically corrected reflectance imagery direct to the users.

Canopy radiative transfer models are applied to the reflectance data to derive canopy variables such as leaf reflectance, LAI, etc. Although many advanced canopy radiative transfer models continue to be developed, they are not as operationally used as the atmospheric correction models. Early models such as SAIL (Verhoef, 1984) derived the canopy reflectance of continuous and homogeneous canopies using only a few variables such as viewing and illumination angles, LAI and leaf angle distribution. More complex models also model the effects of canopy gaps, shadows, soil background, bi-directional reflectance distribution function (BRDF), leaf scattering and absorption coefficients, etc. Examples of recent canopy radiative transfer models are THREEVEG (Myneni and Ross, 1991), LCM2 (Ganapol et al., 1999), FLIGHT (North, 1996), and GeoSAIL (Huemmrich, 2001). The complexity of canopy radiative transfer models makes their analytical solution rather difficult, hence the large number of different models developed to date, many of which are solved using numerical approximations or using various analytical assumptions. The most complex forest scenes to model are those with discontinuous canopies. To deal with the effects of shadowing in discontinuous canopies, a number of geometrical-optical models have been developed (eg. Li and Strahler, 1985, Strahler and Jupp 1990). Using combined canopy radiative transfer and geometric-optical models has proven more successful in modelling effects such as BRDF over discontinuous canopies (Ni et al., 1999). Given the sparse nature of most eucalypt canopies, hybrid models of canopy radiative transfer and geometric-optical models are more suitable for deriving canopy and species variables.

Leaf radiative transfer models are used to derive leaf structural and biochemical information from leaf spectral data or they are often coupled to canopy radiative transfer models to derive leaf level information from hyperspectral images. Leaf and canopy radiative transfer models have been used widely elsewhere mostly with deciduous and conifer forest species and with homogeneous canopies such as crops and pastures. There has been little or no attempt at validating the existing leaf and canopy radiative transfer models with Australian Eucalypt forest species. Examples of leaf radiative transfer models are PROSPECT (Jacquemoud and Baret, 1990) and LEAFMOD (Ganapol et al., 1998). Another leaf model especially developed for conifer needles is LIBERTY (Dawson et al., 1998). There is a need to develop a leaf radiative transfer model for eucalypt species, especially those with isobilateral leaves. Such a model will be a useful link to canopy radiative transfer models for analysing the canopy reflectance.

7. Future Research

7.1 Leaf-level spectral databases

There is a need for more fundamental work at the leaf level to establish comprehensive reference datasets for radiative transfer modelling and validation work. Although there have been many studies on eucalypt leaf spectra in Australia, these datasets are isolated and the types of measurements and experimental/sampling methods are not consistent across all studies. Furthermore such datasets are not readily available to the scientific community for comparison and modelling works. There is a need for the establishment of a large database of leaf spectral and ancillary data on eucalypt species. Leaf level datasets covering a wide range of eucalypt species and environmental conditions should include leaf reflectance and transmittance spectra, surface and internal structure information, leaf age, site and species information, and detailed leaf biochemistry variables such as pigment content, water content, nitrogen, carbon, protein, cellulose and lignin contents. The availability of such a leaf dataset would offer many advantages for further research on eucalypt species ecology. Firstly, the use of the same standard reference dataset would enable direct comparison of the outcomes of different research projects using new and advanced methodologies. Secondly, having access to a comprehensive set of leaf chemical and physical measurements would not restrict the scope of research projects by having to conduct their own leaf level experiments (often restricted to a small sample size and few variables due to instrument, time and budgetary constrains). An example of a leaf dataset established in Europe is the LOPEX data set (Hosgood et al., 1995). LOPEX continues to be used in many studies (eg. Le Maire et al., 2003 and Ganapol et al., 1999) for radiative transfer modelling and validation work.

Most leaf spectral measurements are made by viewing the leaves from a nadir position only. As such there is insufficient information available on the leaf scattering and absorption phase functions. Spectral measurements at several viewing angles need to be made and reference datasets created for deriving the relationships between viewing angle and the scattering and absorption profiles for different species. This is important for eucalypt species where the leaves hang vertically rather than horizontal (which is often the arrangement for leaf spectral measurements).

7.2 Biochemistry

Hyperspectral remote sensing has already proved a significant advancement in the understanding of plant science through its ability to resolve narrow diagnostic spectral features related to definitive characteristics between species, eg pigment content and leaf structure (Kumar et al., 2001). However, further studies of Australian species are required to identify absorption features and spectra specific to a range of biochemicals: cellulose, lignin, xylan, arabinogalactan, starch, pectins, waxes, in addition to structural changes at the leaf level related to senescence and phenology for a range of species. More basic research is needed to determine biochemical variation at the leaf and canopy scale. In addition, studies are needed to characterise the spectral features associated with phenologic change, leaf biochemical content and algorithms that use specific wavelengths to predict chemical composition.

7.3 Disturbance

Fire frequently occurs in Australia and can have a significant effect on vegetation communities during recovery, most notably increasing canopy cover (Brandis and Jacobson, 2003). Fires create a mosaic of very high spatial and temporal variability which significantly alter tree density and size class distribution of stems (Bowman and Prior , 2004). Such alterations to the vegetation structure are yet another area lacking investigation in terms of spectral characterisation.

7.4 Technique development

There is a current concentration of effort on basic applications, for example, the detection and measurement of various foliar chemicals, species differentiation, forest stand biomass, and the detection of a variety of stress agents. While applications using hyperspectral sensors appear promising, there is still a basic need for more biological validation and interpretation of hyperspectral information before it may be used routinely in remote physiological assessments (Dendron Resource Surveys 1997, Treitz and Howarth, 1999 and Sampson et al., 2000).

Techniques are needed to assist this process. The use of multiple-masking techniques on hyperspectral data may assist to reduce confounding noise during spectral analysis (Xiao et al., 2004). Novel uses of feature extraction and classification need to be explored which utilise new band selection procedures, transformations, unique methods of selecting image endmembers, and new unmixing-based techniques (Landgrebe et al., 2001). Goodwin et al., (2005b) extracted proportions of endmembers within each individual pine tree crown in an attempt to further knowledge of fine spectral components within a crown. This may prove to be a useful approach to better access crown foliar properties, particularly where sparse crowns allow a larger soil fraction, but is currently limited by methods of automatic crown delineation.

The process of integrating different sensors of varying spatial resolutions can be facilitated through the use of hierarchical neural networks (Held et al 2003), whereby similar classes can be combined to improve classification between structural groups, with results further partitioned into more separable classes based on other data properties (eg band transformations) and/or analytical processes. Species discrimination appears to require an appropriate combination of hyperspectral data with elevation and other environmental ìsurrogatesî to accurately map vegetation communities / species.

Radar is a potential alternative to lidar for the extraction of structural information, with the benefits of combining with opical remotely sensed data proposed by several researchers (Kushwaha et al 2000 and Ramsey et al.,1998), but few studies have been conducted other than those using single band radar due to available sensor limitations.

Considerable understanding of species spectral characteristics can be gained by studying single stands of single species where background substances tend to be less variable. A few studies in progress will begin to fill the gap of more ambitious study areas where multiple species associations occur with more complex backgrounds are likely to require improved delineation algorithms.

8. Conclusion

While laboratory data indicate that a response may be observable under field conditions, it does not guarantee it (Myers et al., 1966). The studies reviewed have been conducted primarily at the canopy level where additional complexities at the canopy and airborne scale will be encountered, including : different instrument characteristics (signal to noise ratio and bandpass), atmospheric effects, fractional canopy coverage (influence of soil background), and canopy architecture (leaf area index and leaf angle distribution). Plant canopies are structurally diverse due to unique spatial patterns that different species adopt for intercepting light and even regulating that light (Atwell et al., 1999). For example, there is considerable penetration of sunlight through the canopy of a dry eucalypt forest; conversely in dense rainforest or in a radiata pine plantation, only sunflecks reach the ground (Atwell et al., 1999). The unique nature of eucalypt leaves and open-canopy structure with variable leaf area indices is problematic in scaling up leaf-based measurements to airborne platforms, where factors such as atmospheric and image correction and spatial resolution must be taken into account. Due to the large number of factors that influence canopy variation when viewed at the individual tree scale, to understand species-specific relationships between reflectance and leaf and crown attributes requires can be facilitated by a stepwise investigation of spectral reflectance in an integrated approach to scaling up (Coops et al., 2004).Despite the promise of automated crown detection and species identification, it has been found that not any single method of remote sensing is successful (Cohen et al., 1995, 2001 and Gerylo et al., 1998). It has become apparent that remotely sensed data must be considered at spatial scales together with, or as complement to, multitemporal data, in addition to integration with complementary with data from other sources, such as LiDAR (light detecting and ranging) (Lefsky et al., 2001, Lim et al., 2003 and Wulder et al., 2004), or leaf-level data. Another possibility is the hierarchical nesting of image data to represent different scales of forest information, from individual trees to stand-level, and even larger units (Wulder et al., 2004).

The nesting of data from differing scales in a hierarchy provides tremendous opportunities for gathering site-specific information (Wulder et al., 2004). However, to use this information, researchers must understand the potential and limits of data at high spatial resolution and understand how these newly available data may be integrated with other spatial data sources (lower resolution satellite data, LIDAR data, etc). It is becoming easier to sample, scale and stratify data, with new software released or under development that will allow researchers to characterise ecological attributes with data from a range of scales (Wulder et al., 2004, Lucas and Bunting, 2005). Research related to the ecological modelling of eucalypt species (Kumar and Skidmore, 2000) seeking to determine the correlation between species and environmental factors will prove useful for incorporation to remote sensing studies and further ecological understanding of the distribution of eucalypt species.

In summary, as eucalypt species are distributed over wide geographic and environmental gradients and show a relatively wide tolerance to environmental conditions (Boland, 1984), there is considerable work to be done. This is complicated by the paucity of research on spectral characteristics of eucalypts when compared to comparable research on northern hemisphere species.

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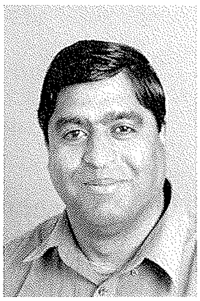
Dr. Laurie Chisholm received the BSc egree in geo;ogy and MA degree grography from the University of Oklahoma, USA, and the OhD degree in remote sensing from the University of New South Wales, NSW, Australia. For her PhD, Laurie used hyperspectral data to investigate the spectral characteristics of a single floodplain forest species, *E.camaldulensis* (river red gum), to changes in a single stressor, moisture stress, including predictive modeling for stress detection at the airborne level.



Dr Bisun Datt received the PhD degree in remote sensing from the University of New South Wales, Sydney, Australia in 1999. He received the BSc degree in physics and mathematics, the PG Diploma in physics, and the MSc degree in physics from the University of the South Pacific, Fiji, in 1985, 1992, and 1996, respectively.

Event Calendar

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ASIA & PACIFIC

6th International Symposium on Web and Wireless Geographical Information Systems
Cho Yiu Hall, University Administration Building, Main Campus, The Chinese University of Hong Kong
December 4-5, 2006
Website: www.dl.kuis.kyoto-u.ac.jp/w2gis06/

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Hyderabad International Convention Centre
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TU Graz, Austria
April 17-20, 2007
AUSTRIA
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Website: www.iv2007.tugraz.at

SSC 2007
Tasmania, Australia
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