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INVESTIGATION OF SPACEBORNE AND AIRBORNE REMOTE SENSING TECHNOLOGIES FOR MAPPING MANNA GUM (*EUCALYPTUS VIMINALIS*) HEALTH IN SOUTH-EASTERN AUSTRALIA

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ABSTRACT: This paper describes the application of three different remote sensing technologies for mapping manna gum (*Eucalyptus viminalis*) in the Mt. Eccles National Park, Victoria, Australia, where extensive over-browsing by the resident koala population has had an adverse affect on vegetation health. Until recently, the only methods available to park managers to assess the spatial distribution of defoliation have been limited to ground survey or expensive aerial surveys. Since the spatial distribution of defoliation caused by koala browsing is relatively heterogeneous and unclustered, medium resolution satellite sensors do not provide an adequate source of information. However, high resolution imagery acquired by the recently launched *Ikonos* satellite has the potential to provide a cost-effective solution to mapping vegetation health. To achieve the aim of accurately determining the spatial distribution of vegetation health, imagery has been acquired from three different imaging sensors: airborne linescanner, oblique-looking airborne video and the *Ikonos* system. The airborne linescanner data was acquired in three bands (near infrared, red and green) at a nominal ground resolution of 0.75m. The airborne video data was also acquired in three bands (red, green and blue), but at a higher spatial resolution. Pan-sharpened *Ikonos* data was acquired in four bands (near infrared, red, green and blue) at a nominal ground resolution of 1m. In order to maximize the possibilities of detecting individual defoliated trees, it was decided in advance that spectral resolution would be sacrificed in favour of spatial resolution, hence the choice of sensors. Consequently, processing of the image data focussed on developing spatial, rather than spectral, algorithms for detecting areas of defoliation.

1. INTRODUCTION

A challenge for national park managers is to operate with increasingly limited fieldwork resources, while making better management and policy decisions. This paper examines the application of high resolution imagery for mapping vegetation health in the Mt. Eccles National Park, Victoria, Australia (figure 1). Manna Gum is the primary species of interest as extensive browsing by the resident Koala population has an adverse effect on health. From a management perspective, mapping the spatial pattern of tree health serves two important aims. First, it establishes a current baseline of the state of vegetation health that can be used to assess the efficacy of ongoing management practices. Second, identifying patterns of health can be used to better understand the browsing habits of koalas. The latter aim may provide managers with additional information for developing improved mitigation strategies. The recent deployment of high resolution imaging platforms such as *Ikonos* allows managers to extend image analysis techniques to the microscale domain, previously only mappable using ground-based field techniques. This paper presents the results of preliminary research that uses very high resolution (~60cm horizontal resolution) multispectral linescanner imagery to map vegetation health (or crown defoliation). Earlier research at Mt. Eccles attempted to used *Ikonos* satellite imagery for tree health assessment with varying success. The paper first examines the limitations of this technology and introduces the potential role of linescanner and video data for tree health mapping. The use of linescanner imagery attempts to overcome some of the limitations of *Ikonos* satellite imagery for mapping vegetation health.

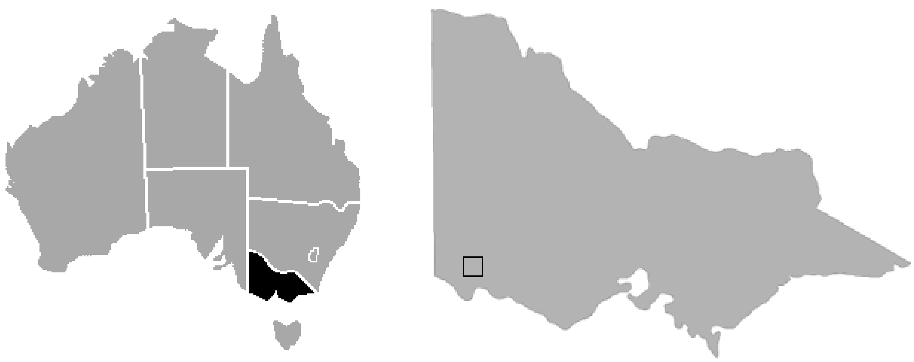

FIGURE 1. Location of the Mt. Eccles study site in Victoria, Australia.

High resolution imaging platforms introduce a suite of new challenges both conceptual and technical. From a technical perspective the large image size and demands for horizontal spatial accuracies challenge our analysis capabilities. Conceptually, a major challenge to emerge from this research is the challenge for park managers to make management decisions at such high resolutions. For instance, the use of medium scale resolution imagery such as Landsat or SPOT inherently includes a level of spatial generalisation that makes management decision-making more feasible. These issues of cognitive interpretation and the implications for decision making are critical for the long term acceptance of such high resolution technologies.

2. STUDY SITE AND PARK MANAGEMENT ISSUES

The Mt. Eccles National Park is located on the volcanic plains of south western Victoria, Australia. The park comprises approximately 6000 hectares of almost pure Manna Gum woodland and is classified as a Category 2 protected area in the United National List of National Parks and Protected Areas. It contains the most diverse collection of volcanic features in south eastern Australia, and is on the register of the National Estate in recognition of its outstanding natural heritage value (DNRE 1996). Much of the park consists of Manna Gum (*Eucalyptus Viminalis)* with the occasional presence of Blackwood (*Acacia melanoxlyn)*, Tree Everlasting (*Ozthamnus ferrugineus*) and Cherry Ballart (*Exocarpus cupressiformis)* (Marchant 1999). The understorey of the woodland species comprises mostly Bracken (*pteridium esculentum)* and Silver Tussock Grass (*Poa cita*).

The most pressing management issue at Mt. Eccles is the heavy defoliation of woodland tree species (specifically Manna Gum) caused by the resident Koala population. At present, the primary mitigation measure for restoring the health of Manna Gum is a laborious, and relatively expensive, annual Koala relocation program carried out by Parks Victoria. Relocation programs, although not the ideal solution to reducing the threat of defoliation, do provide a publicly and politically acceptable solution to a complex management issue. From the perspective of park management, a key data layer that is required to both plan relocation initiatives, and to monitor the effectiveness of relocation programs, is a baseline of the current tree health.

To further complicate the issue of mapping vegetation health in Mt. Eccles, the spatial pattern of Koala browsing does not lend itself well to traditional medium resolution satellite image analysis and interpretation. Specifically, Koalas appear to randomly select trees to browse and the duration of browsing is variable. Relatively healthy and unhealthy trees are commonly neighbours and even within their individual canopies, healthy branches can coexist with defoliated branches. Some spatial clustering of defoliation does occur, but generally the patterns are random. Such spatial patterns of defoliation challenge the effectiveness of medium resolution satellite imagery to establish a credible baseline of tree health in Mt. Eccles. A long-term and effective tree health monitoring program can only be achieved with higher resolution satellite imagery (sub canopy diameter horizontal resolutions) which is the focus of this current research program.

3. DATA SOURCES

3.1 High resolution *Ikonos* satellite imagery

A four band pan-sharpened *Ikonos* image of the study site was acquired on the 7th June 2000. The image covered a ground area of approximately 100 square kilometres, and had a nominal ground resolution of 1m. The *Ikonos* sensor currently provides the highest resolution satellite imagery that is commercially available. Due to the need to map individual trees, it is the only satellite remotely sensed data that could meet the requirements of this project. Full resolution samples of the *Ikonos* data (RGB and NRG colour composite) are shown in figure 2.

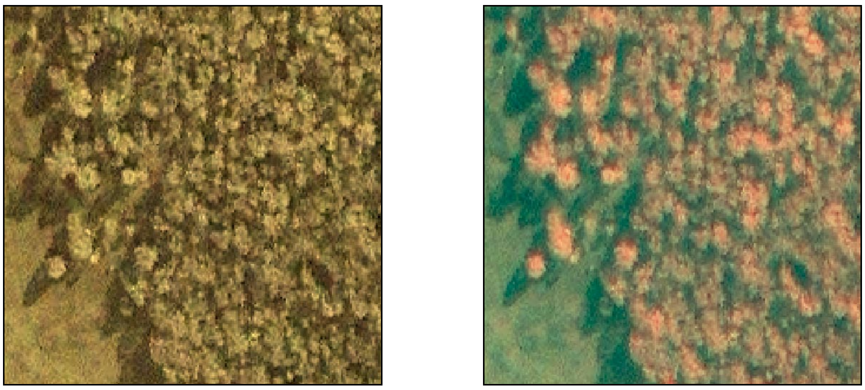

FIGURE 2. RGB *Ikonos* colour composite of Mt. Eccles National Park showing RGB and NIR composite.

3.2 Airborne data

Airborne linescanner data was acquired from the Trispectral Colour Linescanner System of Airborne Research Australia. The instrument was flown on a Cessna aircraft at a height of 500m to 700m above ground level. The resultant resolution of the imagery was between 0.45m and 0.75m.

Oblique looking (30° look angle) airborne video was acquired simultaneously to the linescanner data. The principal reason for acquiring the video data was to enable better interpretation of the linescanner data. The video data comprised of a sequence of images recorded at a rate of 2 Hz. Each individual image was time stamped to ensure that it could be accurately correlated with the ephemeris data of the platform. Although the forward motion of the platform gave some motion blurring effects in the video data, manual interpretation of the imagery was possible. Automatic interpretation will be a subject for future research. Figure 3 shows examples of the linescanner data (left) and the video data (right).

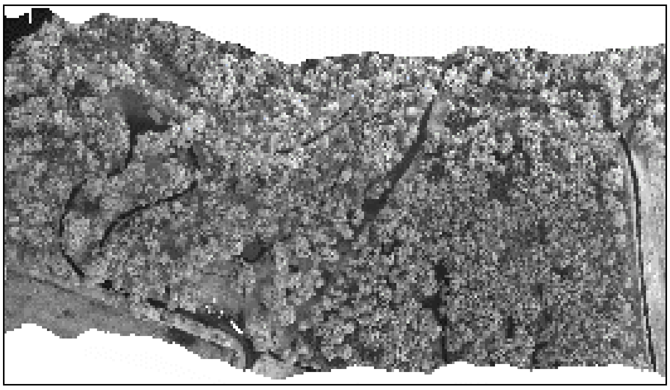

FIGURE 3. Samples NIR band of the linescanner data (left) and video data (right).

3.3 Ground sampling strategy

Earlier research has shown that selecting an appropriate sampling strategy is important as the accuracy of a thematic map depends on the ability of the user to extrapolate successfully between the training areas to the entire map area (Thomas and Allcock 1984). One geodetic control point was established within the national park to provide reference points for differential GPS which was used during the ground truth stage and during image rectification. Owing to the canopy effect of the woodland species in the park, differential GPS proved to be a relatively ineffectual technique for locating *in-situ* observations. To overcome this limitation, a combination of GPS control points and plane surveying techniques using a total station theodolite was used. Samples were chosen by radiating from the location of the theodolite. The locations of over 213 defoliated trees were measured to an accuracy of less than 1 metre for nine sites in the park. Two different survey techniques were used to map individual trees including:

1. a detailed assessment that included recording tree location, tree health, taking canopy photographs, recording the diameter at breast height (DBH), crown diameter, and tagging the tree with a unique identifier for ongoing monitoring; and,

2. a rapid assessment technique that only recorded tree location and tree health for each tree.

The two techniques capture very similar tree data, but their field efficiency is significantly different. For instance, utilising the second technique, one tree could be mapped almost every minute. The first technique required approximately ten minutes of field time to capture the required information. The GPS and survey data was post processed and integrated into an ArcView GIS for subsequent analysis. Furthermore, the locations of nine ground targets were surveyed in order to improve the accuracy of the geometrically rectified linescanner data.

4. DATA PROCESSING

4.1 Geometric processing

The *Ikonos* imagery used in this project was a "Carterra Geo" product. Pixels were resampled to 1m × 1m, and projected onto the WGS84 ellipsoid in UTM zone 54 by the data supplier (Space Imaging Inc.). Due to the viewing geometry at the time of acquisition (50° elevation), the ground sample distance (GSD) of the data was in fact 1.34m along scan and 1.06m across scan. Since the data was pansharpened using nominally 4m multispectral data, the resultant image resolution would have been significantly degraded (Vrabel, 2000). A realistic estimate of the GSD of the *Ikonos* data used in this study is 1.9m (cross-track) and 1.6m (along-track). Due to the low level of geometric pre-processing, pixels could be up to 50m from their true locations, even without taking terrain effects into account. Terrain for the study area ranged from 60m to 110m above the datum. However, for the majority of the study area, the vertical height range was less than 10m. A total of seven ground surveyed control points could be identified in the *Ikonos* imagery. The vertical distribution of these control points ranged from 60m to 80m above the datum. Consequently, a 2D to 2D transformation was considered sufficient to rectify the *Ikonos* imagery. An affine transformation was performed, using all seven points. To validate the accuracy of the rectification result, the transformation was repeated using fewer points with the remaining points being used as independent check points. It was determined that the root mean square residual in x and y were 0.7m and 3.0m respectively. (The discrepancy in x and y is principally due to the fact that terrain induced distortions are manifested in the cross-track direction.) Even so, this level of accuracy was considered sufficient to locate individual trees in the *Ikonos* imagery according to their position measured in object space coordinates.

The airborne linescanner imagery was supplied as orthorectified image strips. The width and length of each strip was defined by the field of view of the sensor and the length of a single flight line respectively. As a consequence of the ungainly dimensions of each image strip (500m × 8km), smaller regions were cropped from the overall data set. These regions were centred on areas where most of the ground survey work had been completed. Even though the data was already orthorectified, it was necessary in some of the selected regions to locally shift the imagery using the ground control points. In all cases these shifts were never more than 6m.

The airborne video data was acquired in order to aid interpretation of the linescanner data. For this reason it was considered inappropriate to perform any geometric correction of the data. Even so, it was possible to determine the geometric location of each frame, using the ephemeris data of the platform and the time code stamp on the video data, which facilitated ground truthing.

4.2 Radiometric processing

Due to the very different viewing conditions, it was decided that the two primary data sources (*Ikonos* and linescanner) should be processed in isolation. For each one, the same methodology was applied: different combinations of bands were used to create various image products, after which manual and automatic interpretation methods were applied. Specifically, the image products generated were: true colour composite (*Ikonos* only); near-infrared false colour composite; normalized difference vegetation index; photosynthetic vigour index; iron oxide index (*Ikonos* only); and principle components. The interpretation methods consisted of supervised and unsupervised classification, segmentation and automatic tree crown detection, as well as manual interpretation.

5. RESULTS

5.1 *Ikonos*

As a consequence of the large look angle of the *Ikonos* sensor (40° from the vertical) and hence the poorer than anticipated GSD (~2m), the *Ikonos* data proved less useful for detecting tree health than anticipated. Although individual tree crowns could be detected, their internal structure was difficult to resolve. This was further aggravated by unfortunate lighting conditions: a low sun angle, harsh shadows and a band of haze in the image. Even so, despite these complicating factors, it was still possible to extract useful information from the *Ikonos* data. Due to the high spatial resolution of the *Ikonos* image, there are large differences between both colour and brightness within a land cover class. For instance, grass and pasture, which would commonly appear homogenous with other sensors, shows a variety of spectral differentiation. In addition, the relatively low sun angle meant that any small differences in vegetation height also caused shadowing.

The overall classification accuracy using the *Ikonos* imagery was in excess of 70.0%. Five vegetation health classes were used to map in-situ observations using a modified Grimes scale (Grimes, 1987). These were consequently compared to the results obtained from a supervised classification of the *Ikonos* imagery. Where misclassifications did occur, the classification variation was in the order of only one vegetation health class. Although these results are relatively promising, a number of confounding issues challenge the validity of the results derived from the *Ikonos* sensor for high resolution tree health assessment. First, the poorer than anticipated GSD meant that correlating *in-situ* health classifications with image classifications introduces inherent uncertainty. This may be generating the higher than anticipated classification accuracies. Secondly, as the later acquisition of linescanner and video data has shown, the prevalence of defoliation is so extensive at Mt. Eccles, that statistically, there is a very high likelihood of encountering a defoliated tree. And finally, the *Ikonos* image had been 1 metre pan-sharpened from 4 metre multispectral data and hence spatially, the data was relatively more coarse than first anticipated. For example, the spectral classification was made difficult by the common occurrence of a relatively vigorous bracken understorey within close proximity to unhealthy trees. Although the *Ikonos* imagery potentially provides an excellent platform for vegetation health assessment, its inherent limitations caused us the question the validity of the results.

5.2 Airborne linescanner

As expected, the airborne linescanner data proved to be much more useful for mapping defoliation on an individual tree basis than the *Ikonos* data, even though the latter had a greater spectral range and resolution. The greater spatial resolution (0.6m) of the linescanner data enabled the internal structure of tree crowns to be mapped, and hence the degree of defoliation could be assessed. Although a range of different composite image products were generated, attention was focussed on NRG false colour composites, NDVI and principal components. These three image products were the most successful at highlighting defoliated trees. Figure 4 shows the principal components of a sample of the linescanner data with ground survey data overlaid.

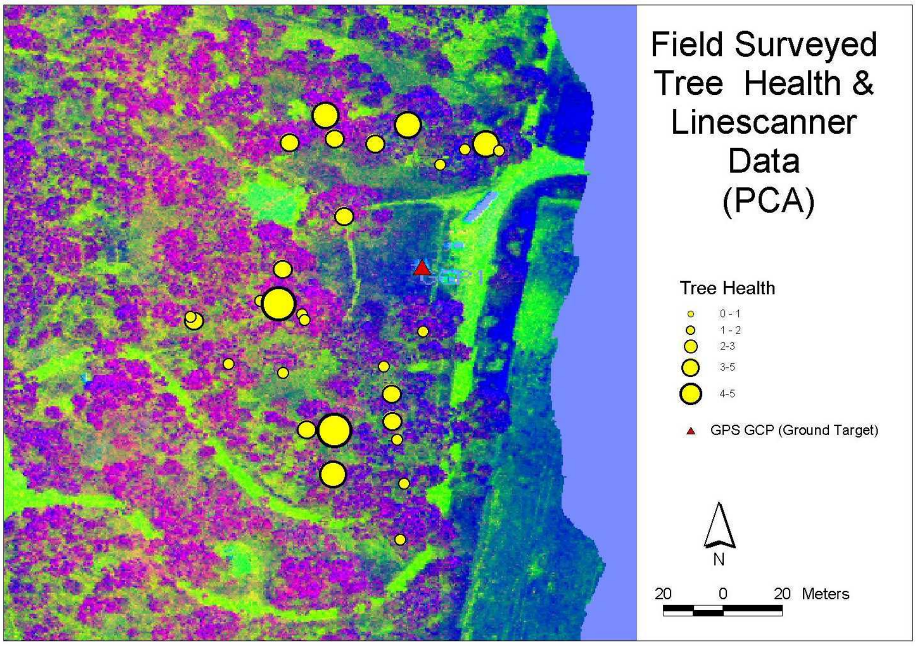

FIGURE 4. Principal components of linescanner data.

On the day of data acquisition, inclement weather resulted in low solar illumination and hence low radiometric resolution, causing the raw linescanner imagery to appear dark. This lack of radiometric resolution in the linescanner imagery led to limited information being extracted from image ratios such as NDVI and photosynthetic vigour. Although the NDVI image required some histogram manipulation to highlight canopy structure, it provided more information than the photosynthetic vigour index which was of limited use, despite being significantly enhanced. The principal components of the linescanner imagery (figure 4) appeared much more promising in revealing the structure of the forest canopy. The first principal component highlighted the structure of eucalypt tree crowns while the second component highlighted gaps within the canopy as well as understorey variation. The third principal component contained very little spatially coherent information.

It is clear that the linescanner imagery provided superior spatial resolution compared to the *Ikonos* imagery, but the *Ikonos* imagery provided more radiometric information across four spectral bands. Therefore, for future research it would be useful to combine the *Ikonos* imagery (with superior radiometric characteristics) with the linescanner imagery (with superior spatial resolution). However, combining both data sets would require significant geometric image processing. Furthermore, while the general radiometric characteristics of the *Ikonos* sensor are preferred, the spectral characteristics of the particular *Ikonos* data set used in this project were suspect. What appears to be a haze band across the centre of the *Ikonos* image has resulted in significant spectral variation across a forest canopy that is known to be relatively homogeneous.

6. CONCLUDING REMARKS

This paper has introduced the problem of detecting defoliation caused by koala browsing and has presented some early results of applying remote sensing and spatial analysis technologies. The heterogeneous nature of the defoliation naturally precludes the use of medium resolution imaging sensors. Therefore high resolution satellite imagery, airborne linescanner imagery and airborne video were investigated. As anticipated, spatial resolution proved to be more important than spectral resolution in detecting defoliation of individual trees. This was shown by that fact that even though the *Ikonos* data had greater spectral resolution and range, it proved less useful for detecting defoliation than the linescanner data. The crown diameter of a typical healthy manna gum tree is approximately 5m. Under ideal circumstances, *Ikonos* data of 1m spatial resolution should have been sufficient to resolve some internal structure of individual tree crowns. However, this was found not to be the case, principally because the actual (rather than nominal) resolution of the *Ikonos* data was in fact closer to 2m. The 0.6m resolution linescanner data was sufficient to resolve the internal structure of the crowns, and therefore successfully detect defoliation, even though its spectral resolution was limited. The resolution of the video data was higher than the linescanner data, but variable across each image frame, due to the oblique look angle and motion blur. Although it proved useful for aiding the interpretation of the linescanner data, as a stand-alone data source for defoliation detection its potential would be limited. Therefore, the linescanner data proved to be the best source of data, giving the optimum balance between spatial and spectral resolution.

Although this paper has focused on the technical issues of image analysis, some important decision making concerns arise with the advent of high resolution imagery. Interestingly, the provision of the results of the *Ikonos* tree health classification challenges a manager's ability to make management decisions at such spatial scales. For example, results can now be presented at the individual tree scale, where in the past the resolution of platforms such as Landsat and SPOT have inherently generalised the results, and hence the spatial scale of decision making. Additional research work is required to provide accurate multi-scale approaches to image analysis that can support environmental decision making. In a broader sense, the ultimate objective of this work is to develop an accurate, repeatable and affordable methodology that can be used for ongoing health assessment in national parks to compliment the existing ground based mapping campaigns.

7. ACKNOWLEDGEMENTS

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