Assessment of *Eucalyptus Wandoo* (Wandoo) and other tree canopy decline using Landsat Trend Analysis

by

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EXECUTIVE SUMMARY

Within this project the objective was to evaluate the effectiveness of using a time sequences of satellite imagery to locate trends in vegetation cover across nominated locations of *Wandoo* woodlands within the south-west of Western Australia. The evaluation required the implicit use of Landsat Thematic Mapper (TM) data to generate spectral indices which then could be displayed to highlight anomalies in spectral responses of the *Wandoo* cover. The time sequence of the imagery was from 1988 – 2005 and had been pre-processed and calibrated to ground Percentage Foliage Cover (PFC) prior to producing Trend Cover Maps for each of the locations.

The locations were the forest blocks and forest areas of the south-west known as, Helena Forest block, Julimar Conservation Park, Drummond Nature Reserve and Dryandra Woodland Reserve. All locations are characterised by mixed woodlands of either heath, Wandoo, Marri, Jarrah and Mallet trees.

An established method was applied to the satellite imagery to detect long-term changes in woody vegetation cover and clear trends in vegetation cover densities were established from the analysis. A key factor in using satellite imagery for this purpose is to calibrate the satellite image with data obtained from field observations of crown cover and density. Additionally, stratification of the landscape based on the Wandoo boundaries greatly aided the process. The final product was ground validated for accuracy and was considered to be an effective and useful means of interrogating vegetation changes over time.

Methods developed uses multispectral Landsat TM imagery to detect changes in vegetation density or cover over time. This has the capacity to detect not just changes in vegetation cover, but to also identify areas of vegetation where there is a permanent or long-term decrease in vegetation density. The information is provided as *vegetation trend maps* (see below) which indicate where and when changes in vegetation have occurred. The changes at particular sites can be quantified and compared using *graphical plots* of the responses over time.

INTRODUCTION

Over the last decade a number of Landsat Thematic Mapper (TM) satellite imagery based remote-sensing monitoring programs have been implemented in Australia. These include the Queensland's Statewide Landover and Trees Study (SLATS), the Landcover Change Project of the Australian Department of Climate Change and Land Monitor, a multi-agency project producing information products for land management in Western Australia.

Landsat (TM) satellite imagery has been used to provide valuable monitoring information of changes in vegetation across the region from 1988-2006. The information is derived from the data archive of the Land Monitor Project and jointly supported by 7 state agencies and CSIRO www.landmonitor.wa.gov.au. One of the information products is provided as *vegetation trend maps* which indicate where and when changes in vegetation have occurred (described below). The changes at particular sites can be quantified and compared using *graphical plots* of the responses over time.

Land Monitor produces two types of vegetation change products;

- the extent of perennial or woody vegetation cover and its change through time and,
- vegetation trends over time (vegetation status), which summarises vegetation history from multiple changes.

The vegetation trends use multispectral Landsat TM imagery to detect changes in vegetation density or cover over time. The method uses a developed 'Vegetation Index', which is related to vegetation cover to show or estimate cover variations. This method has the capacity to detect not just changes in woody vegetation cover, but to also identify areas of woody vegetation where there is a permanent or long-term decrease in vegetation density.

Tree deaths and declines are worldwide phenomena, and linking causal agents to decline events are problematic. In some instances, such a sudden oak death (SOD) caused by *Phytophthora ramorum* and chestnut blight (*Cryphonectria parasitica*), identifiable pathogens causing the death of trees could be isolated (Gilbert 2002; Rizzo *et al*. 2002). However, the interaction between host, pathogen, environment and the complexity of multiple-abiotic causes makes it unlikely that attributing a single factor to a tree decline event is possible. Indeed, expression of the diseases caused by pathogens, even when well understood, often requires the favourable interaction between pathogen, host and environment. For example, in modelling landscape-scale spread of SOD in the western United States, expression of the disease was highly clumped, and models clearly showed that forest edges (that promoted high-light requiring understorey host species) predicted disease expression (Holdenrieder *et al.* 2004). In this case fragmentation of oak forests has provided an important role in dispersing and progressing the disease (Holdenrieder *et al.* 2004). The spatial component was the key to understanding the characteristics of deaths across the landscape.

Forest ecologists recognise that together with anthropogenic factors (such as land clearing), the interplay between environment, herbivores and pathogens can help explain the community characteristics and functionality of forested ecosystems (Holdenrieder *et al*. 2004; Davis et al. 1994). It is a dynamic view of forests and one that accepts the role of disturbance in developing spatial and temporal heterogeneity. This is a conceptual model for the development of forest communities, but it is a model that requires an understanding of the distribution of both species and events at a landscape-scale. Managing unwelcome environmental events when they occur, such a tree decline or mass deaths, also requires a clear understanding of the spatial and temporal distribution of the event. Obtaining spatial data, in the form of topographic maps, aerial photography (including high resolution) and remotely sensed information, is now almost routine in managing natural ecosystems, including assessments of tree declines and large-scale deaths such as the wandoo.

Landscape-scale assessments using remote sensing

In recent years remote sensing has been applied to the assessments of vegetation structure and condition for natural resource management over wide areas of southeastern Australia. For example, Catling *et al*. (2001), Coops and Catling (2000;

2004), and Gibson *et al*. (2004) describe procedures for the use of Multispectral Airborne Videography that allow the interpretation of fauna habitat in forests, damplands and heathlands in New South Wales and Victoria. The drawback of these techniques is cost and a very limited archive. The data are often available at very fine scale (as low as 1 metre pixels) and acquisition of high-resolution multi-spectral and hyper-spectral data, and manipulation of the spatial data are both very expensive (Stone and Haywood 2006).

An alternative approach uses satellite remote sensed imagery. Landsat Thematic Mapper (TM) imagery has been used to map forest inventory and change in East Timor (Bouma and Kobryn 2002); the Philippines (Baynes 2004), and in Australia in Queensland (Bruce and Hilbert 2006), New South Wales and Victoria (Lee *et al.* 2002). In Western Australia, Landsat TM has been successfully used to map forest cover in the Kimberley (Behn *et al*. 2001) and in the Midwest, Murchison and Goldfields Regions (Behn *et al*. 2003).

Standard Landsat TM analysis provides a spatial distribution of landscape-scale data, although mapping temporal change has been more difficult to achieve. However, recent developments undertaken by the CSIRO has provided the Department of Environment and Conservation (DEC) with the opportunity to assess vegetation cover changes at landscape-scales by allowing trend analysis of Landsat TM data for the period 1988 – 2005. Recent software developments have provided a landscape-scale monitoring tool for the pastoral industry in the Northern Territory rangelands (Karfs et al 2004). The procedure involves three stages of analysis and interpretation. Firstly, the trend in vegetation at single point reference sites is examined by interpreting the reflectance of two band-widths that relate directly to vegetation cover. The changes observed over time are related to actual events that have occurred at the reference points. For example, the occurrence of fire is clearly visible in these trend analyses. Once on-ground data that describes the strata where vegetation decline has occurred is gathered, interpolation models are developed that extrapolate the point-based spectral data across the entire landscape that is being assessed. An image showing the spatial distribution of decline (and recovery) can then be produced. The final stage involves ground truth assessment of the vegetation cover change images.

This current project aimed to assess this approach to map the epicentres of wandoo (*Eucalyptus wandoo*) decline in the four locations above. These are:

- Helena Valley Forest block;
- Julimar Conservation Park;
- Drummond Nature Reserve; and
- Dryandra Woodland Reserve.

METHODOLOGY

Satellite Imagery

TM data provide routine broad-scale coverage of an area and is ideal for mapping and monitoring change. The ground picture element (pixel) size (25m) is practical for broad-area surveys and gives results appropriate for resolution with at least several trees and shrubs per pixel and several pixels per homogeneous area. The ability to monitoring change also becomes possible with the ability to co-register and analyse imagery from various dates.

Thematic Mapper (TM) imagery has seven bands - bands one, two and three in the visible parts of the spectrum, band four in the near infrared and bands five and seven in the short-wave infrared portions of the spectrum. Band six is located in the thermal infrared part of the spectrum whilst Multispectral (MSS) imagery had 4 four band, bands one and two in the visible, band three in the near-infrared and band four in the short-wave infrared.

It is important to note that there are many causes and interpretations of changes in reflectance that can be seen in the imagery, particularly when dealing with vegetation, and that the physical changes which result in a similar numerical reflectance response will vary with vegetation type and background. As mentioned above, the 25m pixel can contain several trees and shrubs but also background information on soil, shadow and grasses. As the primary aim of the imagery is to provide monitoring data of the perennial vegetation, image capture dates are limited to summer dates when the grasses are in a cured state.

The cloud-free Thematic Mapper images were geometrically rectified to the GDA94 datum and in MGA50 map projection, using nearest neighbour transformation.

Date	Landsat	Pixel Size (m)
20/02/88	TM	**25**
25/02/90	TM	**25**
30/01/92	TM	**25**
19/01/94	TM	**25**
25/01/96	TM	**25**
29/12/97	TM	**25**
13/02/00	TM	**25**
16/12/01	TM	**25**
5/02/03	TM	**25**
19/03/04	TM	**25**
2/02/05	**TM**	**25**

Table 1: Satellite imagery used

The crucial factor in producing spectral maps or enhancements which reliably display vegetation is that the spectral separation of the dense vegetation cover from sparse to no vegetation cover, is large compared to the vegetation variation within classes. If this can be established, then important band combinations or indices, which provide the vegetation density discrimination, can be identified and appropriate enhancements produced.

Index Images

Several large scale projects within Australia, (see below) have incorporated a vegetation index (TM Band 3 plus TM Band 5)/2 with TM Band 3 being the visible red waveband (VIS) and TM Band 5 being in the short-wavelength infrared (SWIR), within their vegetation surveys. In this project the Index image was made from each date using this linear combination and complied into a sequence file.

The calibration of the Index image to ground-cover is required. A technique by Behn 1991, showed a good relationship between measured ground foliage cover to the spectral information of the Index image. The first stage was to use the most current aerial photography to locate a number of ground sites within the study area to give a range of cover densities within the wandoo.

Projected Foliage Cover Images

The best available aerial photography covering each of the study sites was obtained from CALM Geographic Information Services section. The dates of the photography for each site were varied, from 1999 to 2001.

Aerial photography and Arc View (3.2) was used to determine different areas of homogeneous vegetation densities, according to dot grid templates (Figure 2), to locate prospective field sites.

Field Sites

Each of the four locations had a unique number of field sites depending on size, topography, vegetation and access. Enough field sites were chosen at each study site to give an accurate representation of ground information in order to calibrate the satellite imagery with ground measurements. In total there were 92 field sites (ground-truthed reference points) across the five study areas.

Crown Cover Estimates

Crown cover is a measure of the ground area within the vertical projection of the periphery of crowns in an area, assuming that tree crowns are opaque (Behn *et al* 2003). Using this same method Crown Cover for the prospective field sites was estimated on aerial photographs using dot grid templates (Figure 2). The template assumes an open opaque crown. To convert the crown cover to projected foliage cover (which is what the satellite imagery responds to), ground measurements in the field sites were used to establish the degree of actual crown density. Crown cover was also estimated in the field to double check desktop measurements and account for any change or error in aerial photography.

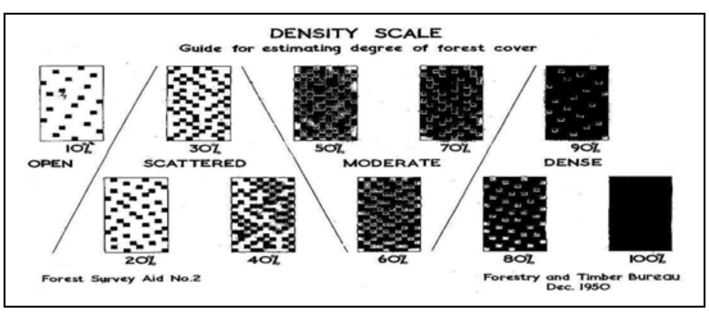


Figure 2: Crown density template (Forestry and Timber Bureau 1950)

For example, Figure 3 demonstrates a field site at Dryandra Woodland Reserve, chosen as it represents an area of homogeneous vegetation cover. Using the density template (Figure 2) this site was estimated at 30% forest cover.

Figure 3. Field site at Dryandra which demonstrating homogeneous vegetation cover at 30% crown density.

Projected Foliage Cover (PFC)

PFC is the percentage of the field site occupied by the vertical projection of foliage. PFC is the product of crown cover and crown density (Behn *et al* 2003). Using the crown cover and density estimates, a PFC value was determined for a number of reference points in each field site (McDonald *et al* 1990).

30 % Crown Cover X 75% Crown Density = 22.5% PFC

Figure 4: Projected foliage cover (PFC) is determined using the values of crown cover and crown density,

Regression

To determine the relationship between on-ground measurements and the Landsat imagery, a regression equation of the mean spectral information from the cover index image was determined as a function of the on-ground values of PFC at the ground-truthed reference points. The regression value is then applied to the cover index image to relate the image reflectance to the predicted PFC.

A Percentage Foliage Index (PFI) image is then created for each site from 1988 – 2005. This gives a 17-year historical sequence of imagery, and the changes or trends over time are then summarised for the time period into linear and quadratic components and estimated independently using orthogonal polynomials (Draper & Smith, ch 5).

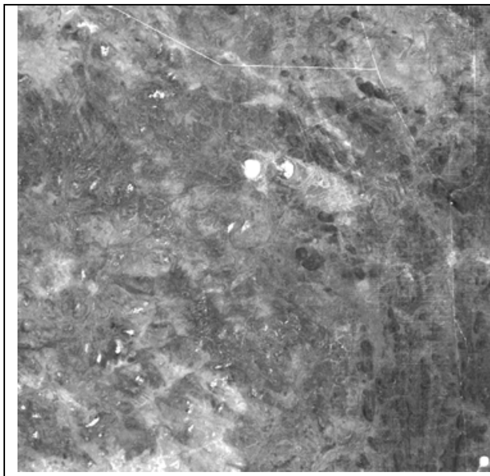
Trend Image

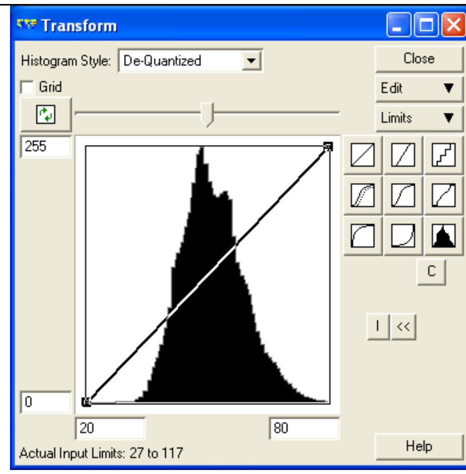
The 'Trend Image' is used to calculate trends (e.g. slope over time) (Wallace et. al, 1999) and any deviations are real numbers and are changes that are produced for each pixel and scaled to fit the 1-byte range of 0-255 for the temporal indices over time.

Slope (linear trend over time)	**Lin coeff * (255/10) + 127.5** *[scales slopes from –5 to +5 into the 0-255 range]*

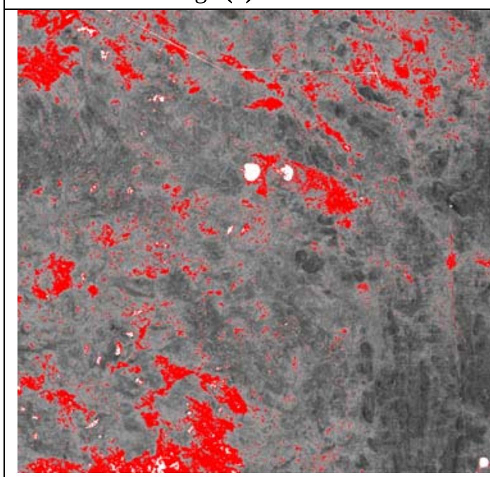
Note that the input values are the PFC values at different dates, so the units for (e.g.) the slope are foliage counts per year.

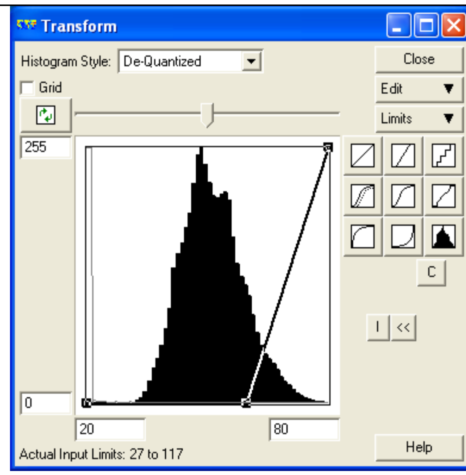
The 'Trend Image' can be displayed to summarise trends and stability of vegetation over time as measured by the PFC index, and in particular to highlight areas with different patterns of change. For this project simple summaries of trends over the period can be made by displaying positive and/or negative linear trends in different colours (see below) while other bands can be used to examine deviations from these trends.



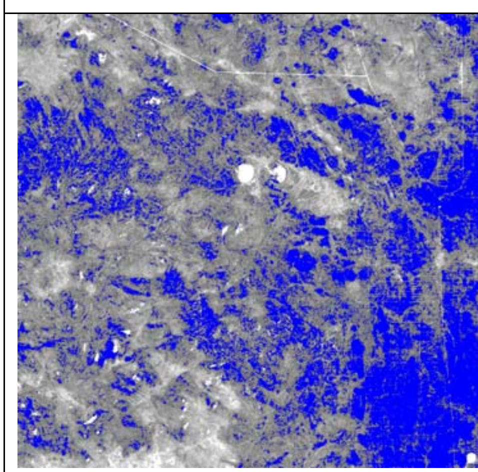


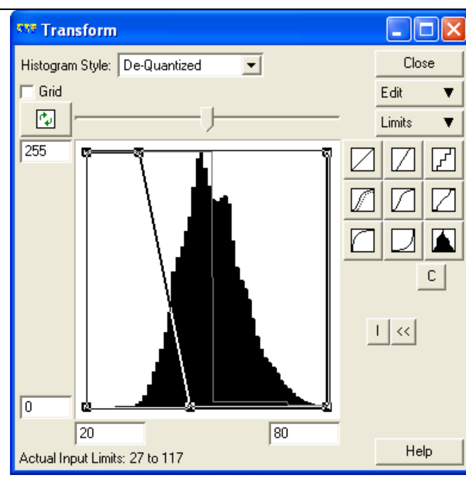
Linear Trend Image **(a)**





Negative cover trend **(b**





Positive cover trend **(c)**

Figure 5: The Linear Trend Image, (a) above shows the vegetation trend cover, for a particular time period and location, with areas of light or white being negative cover trends (shown as red in (b)) and areas of dark or black are positive cover trends (shown as blue in (c)).

RESULTS

Trend Maps

Trend image maps covering the project locations of Helena Valley Forest block (Figure 6); Julimar Conservation Park (which also included the small Drummond Nature Reserve to the east) (Figure 7), and Dryandra Woodland Reserve (Figure 8), were produced.

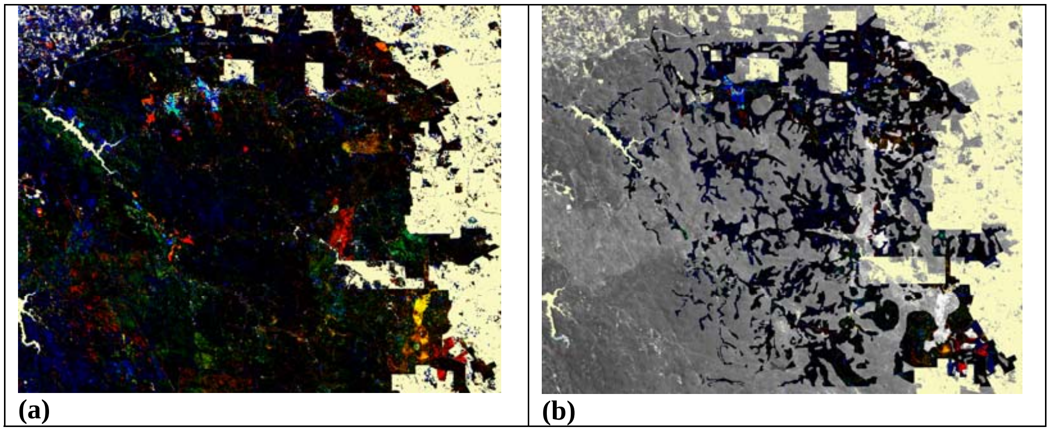


Figure 6. Helena Valley Forest block Trend map **(a)** Entire forest block with red areas indicating vegetation cover loss or decline, blue cover gain and black as stable cover. Causal agents of change can not be determined from this image alone. The forest block was then stratified with existing wandoo boundaries **(b).**

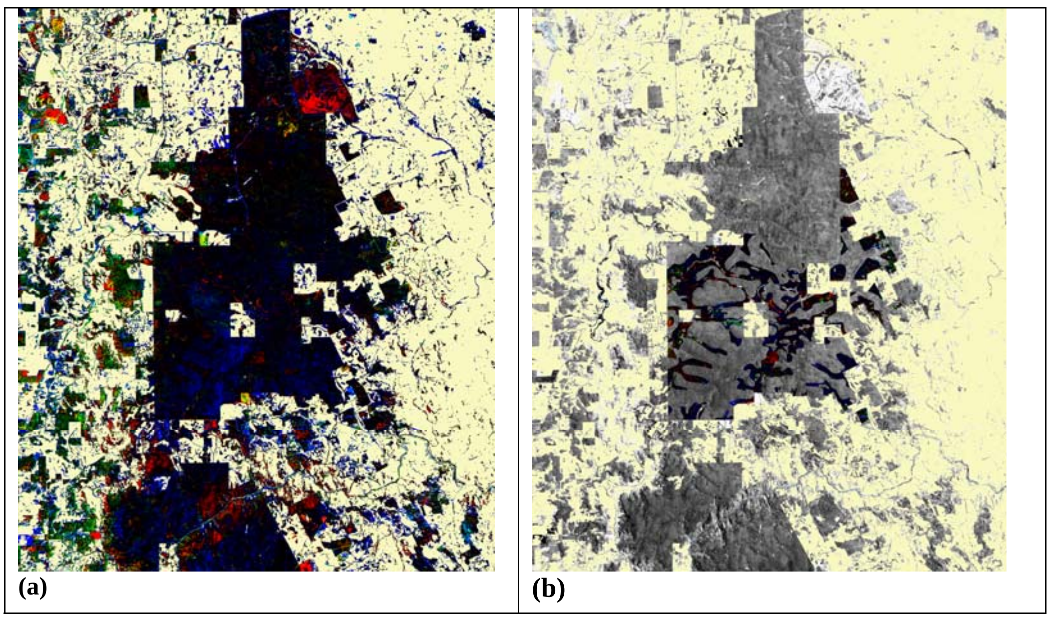
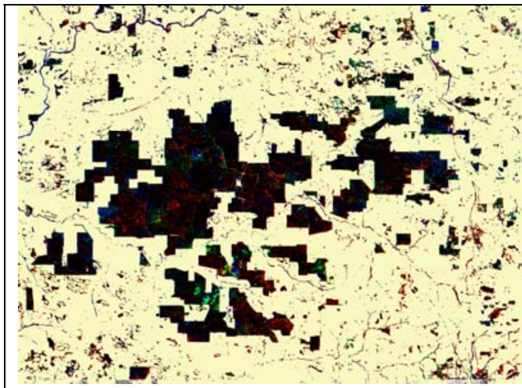


Figure 7: Julimar Conservation Park Trend map **(a)** Entire park with red areas indicating vegetation cover loss or decline, blue cover gain and black as stable cover. Causal agents of change can not be determined from this image alone. The park was then stratified with existing wandoo boundaries **(b).**


(a)

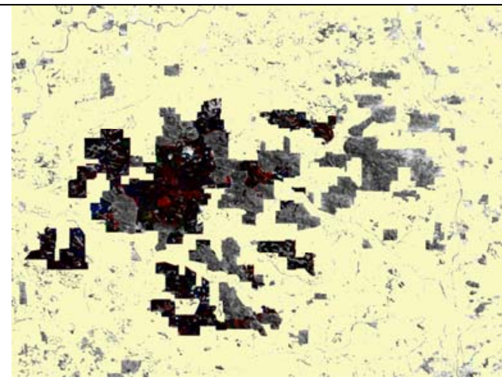

(b)

Figure 8: Dryandra Woodland Reserve Trend map **(a)** Entire reserve with red areas indicating vegetation cover loss or decline, blue cover gain and black as stable cover. Causal agents of change can not be determined from this image alone. The reserve was then stratified with existing wandoo boundaries **(b).**

Accuracy

The proportion of declining, recovering and stable vegetation was assessed for the total area of each site, (Table 2 below) giving the following values. It should be noted that fie boundaries and other known causes of gross canopy change (such as clearing) were ignored in this analysis.

Site	% Increase	% Decline	% Stable
Helena Catchment	4	13	83
Julimar State Forest	8	13	79
Drummond Nature Reserve	4	30	66
Dryandra	14	10	76

Table 2: Proportions of vegetation change at each project study site

The proportion of declining, recovering and stable vegetation was assessed for each site, for the Wandoo occurrence area only, giving the following values:

Site	% Increase	% Decline	% Stable
Helena Catchment	11	17	72
Julimar State Forest	4	17	79
Dryandra	23	18	59

Table 3. Proportions of vegetation change within Wandoo occurrence areas only, at each project study site

Accuracy of the technique was based on *A Priori* selection of ground-truth sites using the spatial models to predict points of canopy loss, canopy increase and no change. On ground assessments of these selected points were then made to determine the accuracy of the spatial model.

Based on the wandoo vegetation community data available within the Department of Environment and Conservation, areas of decline and increase in wandoo canopy are smaller than the areas of stable canopy. Proportions (percentage area) of increasing wandoo canopy in the period 1988 to 2005 range from 4% at Julimar Conservation Park to 23% at Dryandra Woodland Reserve. Proportions of decreasing canopy in the period 1988 to 2005 in wandoo vegetation range from 17% at Helena and Julimar to 18% at Dryandra. Stable (no change) proportions range from 59% at Dryandra to 79% at Julimar.

The trends indicate that canopy loss or decline in wandoo has occurred at a number of locations. The procedure also identified that canopy increases also have occurred. In some of these ‘canopy increase’ sites it would appear that wandoo crowns are re-establishing from epicormic growth. However, over most of the areas (60 – 70%), the canopy appears to be stable.

A Priori selection of trends indicates the technique was correct in predicting a recently declined, an increasing or stable tree canopy (regardless of which *Eucalyptus* or *Corymbia* species) in 60 to 70% of occasions. Reasons identified for failure to correctly predict an event were:

- Incorrect delineation of vegetation communities, or insufficient mapping data defining vegetation communities. For example, significant declines in canopy are apparent at Drummond Nature Reserve. Vegetation data indicated this change was likely to be a decline in wandoo canopy. On-ground assessments determined that gross canopy decline had occurred but that Marri was the species affected. Wandoo canopy in this reserve is healthy.
- Incorrect record or mapping of fire events. If not mapped, fire scars are assumed to be a decline. This occurred at one site in Julimar.
- Boundaries between vegetation communities. Incorrect predictions of canopy loss occurred at several sites in Dryandra at boundaries between mallet plantation and natural vegetation, and also at one boundary between an *E. accedens* and *E. wandoo* community.

Gross changes to canopy are accurately identified using this technique. However, predictions of changes that are related to particular tree species rely on accurate delineation of vegetation communities within the survey areas.

CONCLUSION AND DISCUSSION

Any form of vegetation monitoring requires measurements to be repeatable, consistent and reliable. The spatial, spectral and temporal resolutions of the Landsat series of satellites are at scales particularly relevant, for which these on-ground measurements can be accurately made, and so are well placed to provide necessary and updated information for land managers.

The methodology described here provides a sound basis for rapid, accurate mapping tree cover trends across large areas where the use of conventional aerial photography cannot be economically justified.

Relevant information on vegetation cover trends has direct links to health, condition and change and are of great interest from a variety of perspectives. Satellite imagery, primarily due to its synoptic views of landscapes and multi-temporal sensing, is suited for monitoring this vegetation information. One of the benefits of continued collection of satellite imagery, by programs like Landsat, is the ability to study changes in landscapes over time, with changes in vegetation cover being among the most common features sort. Sidmore *et al* (2002) states, the historical archive of satellite imagery for studying landscape change continues to grow and its duration now covers almost a third of a century. It is unmatched in quality, detail, coverage and importance. This dramatic increase in studies using this archive of historical satellite imagery indicates the growing value of imagery and points to a future where remote sensing data will play a key role in our understanding of how landscapes are changing and how humans are influencing the health of vegetation.

This archive of imagery is a valuable tool for scientists and researchers as they work to gain a better understanding of complexity of our environmental systems. Long-term monitoring information is critical for maintaining the health and safety of our communities, our economy and our environment.

Satellite imagery has been used to provide valuable monitoring information of changes in vegetation across the project area from 1977-2009. The information is derived from an archive w*hich is jointly supported by state agencies, CSIRO, and Federal Department of Climate Change.* The information is provided as maps and digital data which indicate where and when changes in vegetation have occurred.

This information provides a means to produce a comprehensive assessment of the problem, to direct ground work and site selection, to extrapolate from limited field observations, and to locate sites for detailed research work. Knowing the location and timing of affected and unaffected areas may assist in identifying causes of the problem.

REFERENCES

Baynes, J.S., (2004) *Using FCD Mapper software and Landsat images to detect breaks in forest canopies in landscapes in Australia and Philippines*. Proceedings from the ACIAR project planning workshop, Ormoc, the Philippines, 15-17 February 2005, pp. 151-158.

Behn, G.A., McKinnell, F.H., Caccetta, P., Vernes, T. (2001) *Mapping forest cover, Kimberley region of Western Australia*. Australian Forestry Vol. 64, 80-87.

Behn, G., Bardon, A., Raudino, A. & Stoneman, G.L. (2003) *Mapping of Forest Cover in the Midwest, Goldfields and South Coast Regions of Western Australia*. Department of Environment and Conservation and (internal report)

Bouma, G.A, and Kobryn, H.T., (2004) *Change in vegetation cover in East Timor, 1989-1999*. Natural Resources Forum 28, 1-12.

Bruce, C.M, and Hilbert, D.W., (2006). *Pre-Processing Methodology for Application to Landsat TM/ETM+ Imagery of the Wet Tropics*. Cooperative Research Centre for Tropical Rainforest Ecology and Management. Rainforest CRC, Cairns, Queensland, Australia.

Catling, P.C, Coops, N.C., (2004*) Identification of species and functional groups that give early warning of major environmental change (indicator 1.2c*). Part B: report on the efficacy of videography (and other high spatial resolution imagery) for habitat mapping. Report for the Forest and Wood Products Research and Development Corporation, Australian Government, Canberra. 13 pp.

Catling, P.C. Coops, N.C., & Burt, R.J., (2001). *The distribution and abundance of ground-dwelling mammals in relation to time since wildfire and vegetation structure in south-eastern Australia*. *Wildlife Research*. 28:555-564.

Coops, N.C., Catling, P.C., (2000) *Prediction of historical forest habitat patterns using binomial distribution and simple Boolean logic from high spatial resolution remote sensing.* Computers and Geosciences 27 (2001) Pages 975-805.

Draper, N. R. and **Smith. H.** (1981). *Applied Regression Analysis*. New York. Wiley

Davis, J.R., Pavek, J.J., and Corsini, D.L., (2002) *Potato genotypes, a tool for managing soilborne pathogens – a summary*. XXVI International Horticultural Congress: Managing Soil-Borne Pathogens: A Sound Rhizosphere to Improve Productivity in Intensive Horticultural Systems

Furby, S. L., **Renzullo, L. J.**, **Chia, J.** and **Wallace, J. F.** (2004), *The Use of Spectral Indices and Spatially Varying Threshold Surfaces for Mapping the Extent of Perennial Vegetation over Time*, The 12th Australasian Remote Sensing and Photogrammetry Conference Proceedings, Fremantle, Western Australia, 18-22 October.

Gibson, L.A., Wilson, B.A., and Aberton, J.G. (2004), *Landscape characteristics associated with species richness and occurrence of snall nayive mammals inhabiting a coastal heathland: a spatial modelling approach*. Biological Conservation 120 (2004) Pages 75-89.

Gilbert, GS., (2002) *Evolutionary ecology of plant diseases in natural ecosystems*. Annu Rev Phytopathol 40:13–43.

Holdenrieder, O., **Pautasso, M., Weisberg, P.J., and Lonsdale, D.** (2004), *Tree diseases and landscape processes: the challenge of landscape pathology*. Trends in Ecology & Evolution, Volume 19, Issue 8, 1 August 2004, Pages 446-452.

Karfs R.A., Daly C., Beutel T.S., Peel L. and Wallace J.F (2004) Proceeding of 12th ARSPC, Fremantle, WA.

McDonald, R.C., Isbell, R.F., Speight, J.G., Walker, J., Hopkins, M.S. (1990). *Australian Soil and Land Survey Field Handbook.* Second Edition. Inkata Press, Melbourne Sydney

Rizzo, D. M., Garbelotto, M., Davidson, J. M., Slaughter, G. W. and Koike., S. (2002a). *Phytophthora ramorum* as the cause of extensive mortality of *Quercus* spp. and *Lithocarpus densiflorus* in California. Plant Disease. 86: 205-214..

Skidmore, A., Prins, H., (2002) CRC Press *Environmental Modelling with GIS and Remote Sensing*

Stone, C., and Haywood, A., (2006) *Assessing canopy health of native eucalypt forests.* Ecological Management and Restoration 7: S24-S30.

Wallace, J. F., Behn, G. and **Furby, S. L.** (2006), *Vegetation condition assessment and monitoring from sequences of satellite imagery*. Ecological Management and Restoration, Vol. 7, Sup 1, pp 33-36.

Wallace, J. F. and **Thomas, P. T.** (1999), *Monitoring and summarising rangeland changes using sequences of Landsat data.* Proceedings Seventh International Rangeland Conference.