RECENT DEVELOPMENTS IN LANDSAT-BASED CONTINENTAL SCALE LAND COVER CHANGE MONITORING IN AUSTRALIA

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KEY WORDS: Remote Sensing, Land Cover, Monitoring, Multi-temporal, Landsat, Forestry

ABSTRACT:

Land use changes associated with agriculture and forestry are a significant component in Australia's carbon budget. In response to the need to quantify the resulting greenhouse gas emissions, the capability for continental monitoring of land cover changes using Landsat data has been developed through collaboration between the Australian Department of Climate Change (DCC), the CSIRO, and other partners. The project, called the National Carbon Accounting System - Land Cover Change Project (NCAS-LCCP) uses some 5000 Landsat MSS, TM and ETM+ images to monitor land cover attributes including the presence/absence of perennial vegetation, plantation types and urban extent, at 25m resolution for fifteen time periods since 1972. The derived information is used to inform carbon accounting, environmental reporting and management. The original demands for the spatial and temporal resolution used arose from the development of the reporting rules (Marrakech Accord) guiding the implementation of accounting procedures for the Kyoto Protocol. However the remote sensing program evolved to more broadly cover interests in monitoring land use change generally. To meet Australia's current definition of forest, a land cover must have 20% tree crown cover and the potential to reach greater than 2m in height. However, there are large areas of Australia where vegetation communities do not meet this canopy density threshold, such as the drier rangeland regions or within agricultural regions. Increasingly there is a requirement to map and monitor current and historical changes in such areas, at regional and national scales, to provide information for conservation and natural resource management questions. Landsat Thematic Mapper data from 1989 to the present is being used. Sparse perennial vegetation cannot be reliably discriminated from other ground cover types based solely on the spectral information in this data; however by including information from image texture the results can be significantly improved.The timing and extent of land cover change (to or from forest) is important for accounting of carbon fluxes. In areas where new forest growth has been identified, the carbon modelling can be improved by using growth data specific to the new forest type. Given new forest, forest type (hardwood and softwood plantations, environmental planting and native regrowth) is of interest. Research was undertaken to examine whether an operationally feasible methodology for labelling the type of new plantings could be developed using the existing time series of Landsat imagery. An operational methodology for mapping new post-1990 plantation type was developed using Landsat TM imagery, but the method could not be applied to pre-1990 forest types due to the reduced discrimination using Landsat MSS imagery. An alternative strategy was developed using the spectral growth patterns of different plantation types through the time series to best separate them from native forest.This paper will present the results from the recent pre-1990 plantation mapping and sparse cover monitoring activities which are now being implemented at national scale in the NCAS-LCCP program.

1. INTRODUCTION

An understanding of the change in land cover to detect afforestation, reforestation and deforestation events is fundamental to the accounting for carbon change in forestry and agriculture. The impact of an event associated with land cover change may continue over many years and vary with time since the event took place. It is, therefore, necessary to be able to monitor change in land cover over extended periods of time. In response to the need to quantify the resulting greenhouse gas emissions, the National Carbon Accounting System - Land Cover Change Project (NCAS-LCCP) has developed the capability for continental monitoring of land cover change using Landsat imagery through collaboration between the Australian Department of Climate Change (DCC), the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and other partners.

The original demands for the spatial and temporal resolution used in the Program arose from the development of the Marrakech Accord (UNFCCC, 2002) reporting rules guiding the implementation of accounting procedures for the Kyoto Protocol, with particular emphasis on forest extent and changes. The system accounts for emissions from forest conversion since 1972, including emissions resulting from the loss of soil carbon and decay of vegetation that was deforested in previous years. The relevant decay cycle covers a period of 20 years. The amount of regrowth vegetation and removal of regrowth is also critical for determining net emissions. The development of the modelling components and data requirements for Australia's carbon accounting system is described by Brack *et.al.* (2006).

With its temporal coverage (15 epochs) and spatial resolution (25m) of the Australian continent, the NCAS-LCCP is one of the largest land cover monitoring programs in the world. Over a comparable spatial extent, the European CORINE and US national land cover datasets each consist of two epochs separated by a decade. Global monitoring programs tend to operate at coarser spatial resolution. The Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD), for example, plans to operate at 250m to 1km spatial scales for land cover change with periodic monitoring of regional areas at finer scales (20-30% of the forested areas per year).

The NCAS-LCCP is based on the consistent application of documented, quantitative processing procedures with rigorous quality assurance steps throughout the processing sequence.

The current operational monitoring system includes the following components: registration of time-series Landsat data to a common spatial reference; calibration of Landsat data to a common spectral reference, including bi-directional reflectance distribution function (BRDF) correction; processing of the calibrated data to adjust for viewing geometry effects including differential terrain illumination, if required; processing of the calibrated data to remove 'corrupted' data, which include dropouts, data affected by smoke and cloud; stratification of the data into 'zones' where land cover types within a zone have similar spectral properties; analysis of ground and satellite spectral data to determine, for each date, a classifier and its parameters (thresholding); specification of a joint model for multi-temporal classification, and hence change detection; and validation of the classifications to quantify their accuracy. The methodology and its evolution are described by Caccetta et al (2003, 2007) and fully detailed specifications for operational processing for the system are given in Furby (2002). Under a framework of contracts and quality assurance procedures, commercial companies apply these methods to the growing archive of Landsat images.

The initial implementation of the forest extent and change mapping program was completed in 2002 producing forest extent and change products from 1972 -2000. These products are regularly updated with more recent imagery, now on an annual basis. The methodology and results are continuously reviewed with respect to technological development and computational efficiency.

Subsequent to the initial mapping of forest presence/absence, the monitoring program is expanding to include the mapping for plantation type (softwood or hardwood) for both post-1990 Kyoto compliant plantings and pre-1990 forest inventory; monitoring of sparse woodland (5-20% canopy cover) and urban change to meet both carbon accounting and natural resource management needs.

This paper presents the results from the recent sparse cover monitoring and pre-1990 plantation mapping activities which are now being implemented at national scale in the NCAS-LCCP program.

2. PRE-1990 PLANTATION MAPPING

The forest categories of interest are hardwood and softwood plantations, environmental planting and native regrowth. Existing GIS data for forest / plantation class is of variable quality, inconsistent within and between states, irregularly updated and often at inappropriate spatial scales for integrating with the forest cover mapping. Detailed data is held privately for some areas by forestry related businesses. Nationally consistent forest type classifications are not available at an appropriate spatial and temporal scale for use in the carbon modelling.

Research was undertaken to examine whether an operationally feasible methodology for labelling the type of new (post-1990) and existing (pre-1990) forest cover could be developed using the existing time series of Landsat imagery. The studies showed that softwood and hardwood plantings could be discriminated from native regrowth using Landsat TM image data. The spectral information for new plantings is averaged (composited) through the time series and the composite image is classified. The methodology adopted is described in Chia et al, 2006. Post-1990 plantation type maps were first produced in 2004 and are now updated annually together with the forest extent and change mapping.

There was significantly less discrimination between softwood and hardwood plantings and native forest when considering only Landsat MSS imagery. However, in many cases mature softwoods are spectrally separable from other forest types, as shown in Figure 1. Canonical variate analyses (CVA) (Campbell and Atchley, 1981) were performed to investigate the spectral separability of softwood plantations from other forest types. A CVA provides a transformation of the data that maximises between class separation relative to within class variability. Figure 1 shows a canonical variate means plot for a typical region – the Gippsland, Victoria region located in the south-east of Australia. The softwood (pine) training sites were selected to cover a range of growth stages from just planted to mature. The 'native' forest sites were selected to cover a range of forest densities / conditions as well as the range of forest types including state forest on predominantly mountainous terrain, remnants and reserves within the flatter agricultural region and riverine and coastal vegetation.

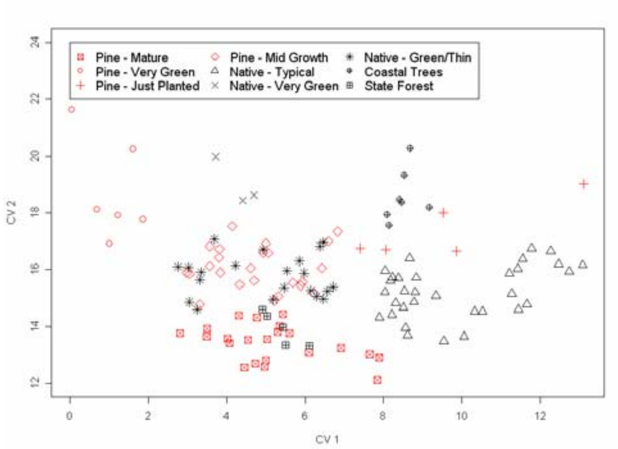


Figure 1: Canonical variate means plot for 1988 Landsat MSS data from the Gippsland region in south-eastern Australia. Softwood (pine) training sites are shown using red symbols and other forest types shown using black symbols. The symbol types vary according to plantation age or native forest cover type.

Figure 1 shows that the mature softwood sites cluster together and are separable from all but the state forest sites. Also separable are the group of softwood plantations with very green flushing vegetation, which is typical of very young softwood plantings. The typical native forest areas, the coastal trees and the very green native forest are all separable from the softwood sites, although there is some potential overlap with the very bare newly planted softwoods. Most of the overlap is between thinner native cover with either a bare or green understorey and softwoods during the early and middle parts of their growth cycle. Such spectral separability is typical of most of the regions in which the plantation type mapping is required.

Softwood plantations are separable from most other forest cover types both early and late in their growth cycle, but are often less separable in the middle period. It was also observed that greener or mountainous native forest is often confined to distinct geographic regions that can be separated from the regions of plantations using stratification zones or by subsequent manual attribution of the results. Thinner native forest becomes more separable from mid-growth softwoods by considering their growth patterns across several years. Native forest that is naturally thin will stay about the same over many years. Native forest that is thin due to disturbance (fire or disease) will be easier to discriminate as it matures or recovers into more typical native cover. As the softwoods become more mature, they become more separable.

This spatial and temporal information was combined with the spectral information in the following classification steps:

1. Stratify each map sheet into zones within which the softwood plantations and background forest types are homogenous and as separable as possible from each other.
2. Within each stratification zone, classify the area mapped as forest in each epoch as softwood plantation or native forest using maximum likelihood classification.
3. Apply a joint model for multi-temporal classification.

As well as each available Landsat MSS epoch (1972, 1977, 1980, 1985 and 1988), the closest relatively cloud-free and dry Landsat TM epoch was also included (e.g. 1989, 1991 or 1992). The Landsat TM imagery served two purposes. Firstly, it usually provided greater discrimination between the forest cover types and hence additional information in regions where the Landsat MSS signal was ambiguous. Secondly, the results from the multi-temporal processing are usually less accurate for the epochs at the beginning and end of the time series as they have fewer adjoining image dates. By including the Landsat TM epoch, the final Landsat MSS epoch was no longer at the end of the time series.

2.1 Single date classification

Maximum likelihood classification (Rao, 1966) was applied to each single-date image. These classifiers generally assume that spectral descriptions for classes can be modelled using multivariate Gaussian densities. The key outputs from this implementation of the classifier were the posterior probabilities of belonging to each spectral group for each pixel in the image. In preparation for the multi-temporal processing, the spectral groups were grouped into four cover classes based on inspection of the classified images. The cover classes were:

Softwood: Contained predominantly softwood plantations and only unavoidable commission errors (e.g. small patches of state forest in the Gippsland example). We expected reasonably high accuracy of areas mapped as softwoods, although there may be significant omissions (e.g. mid-growth cycle plantings).

Native: Contained predominantly the non-softwood forest types. We expected a reasonably high accuracy as a map of native forest, although there may be omissions.

Mixed: Formed from spectral groups that map pixels of both softwood and native forest types (e.g. thin native forest and mid-growth softwoods). Individual circumstances determine whether this cover class is slightly more likely to be softwood or native or too mixed to tell.

Bare: Almost bare ground with too little tree cover to determine spectrally whether it will grow into softwood or native cover.

The fundamental difference between the 'bare' and 'mixed' cover classes was that bare had the sense of not enough cover to classify and hence 'don't know', whereas mixed may have had some tendency towards either softwood or native.

The four-class probability images for each epoch were masked using the corresponding forest extent layer so that all areas not mapped as forest were excluded (set to null in subsequent calculations). Such non-forest areas have a range of cover types, from agriculture to urban infrastructure, that have no bearing on what type of forest, if any, that may have been present before or after any given epoch.

An assessment of the accuracies of these land cover classes was also made. Ideally the assessment would have been made using reserved ground data from that epoch; however in practice accuracy rates were estimated by a visual assessment of the four-class probability image against the areas of apparent plantations and native forest in the satellite imagery as there was barely enough ground data to train the classifier. For the purpose of the multi-temporal processing, it is sufficient to have correct relative accuracies, i.e. is the 1985 classification more accurate, less accurate or about the same as the 1988 classification.

2.2 Multi-temporal processing

To improve the single-date classification accuracies, data from the whole time series were combined to refine the classification at each epoch and to provide temporal consistency. There were only two output classes from this stage in the processing: 'softwood' and 'native'.

Bayesian networks/conditional probability networks which are parameterised as Conditional Gaussian distributions were used. The scheme for combining data is based upon techniques presented in Lauritzen and Spiegelhalter (1988, 1992). The application to land cover monitoring is described in Kiiveri (2003). A network can be represented by a graph, where the nodes of the graph represent random variables and the edges of the graph represent (conditional) independence assumptions between the variables. Advantages of this approach include integrating the data in a way that allows for varying quality / accuracy of the inputs, handling missing data (cloud or no imagery) by using all available information to make predictions and calculating uncertainties in the outputs.

The network used is shown in Figure 2. The inputs were the four-class probability images from the single-date classifications (square nodes in Figure 2). The outputs (circles) were the two-class softwood/native probability images. The edges represent relationships between the nodes. The vertical edges are the error rates, i.e. how well the single-date classification represents the true softwood/forest map. These were estimated from each individual classification and varied according to the image quality and seasonal issues that affected the discrimination between softwood and native classes. Typically the Landsat MSS classifications were considered less accurate than the Landsat TM classification, the 1972 and 1977 classifications tended to be less accurate than later years and the classifications from some very green images were also down weighted. The horizontal edges are temporal rules, representing what we expected a particular softwood/forest map to look like given the true before and after maps.

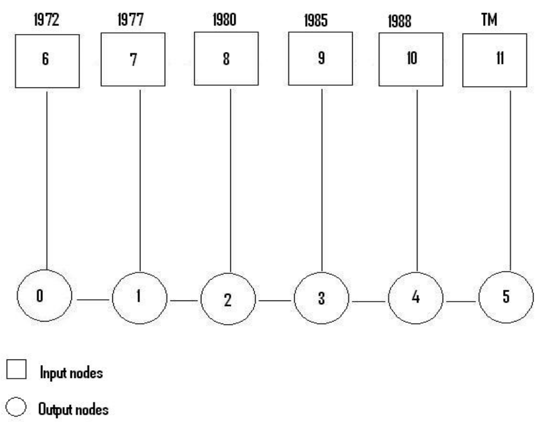


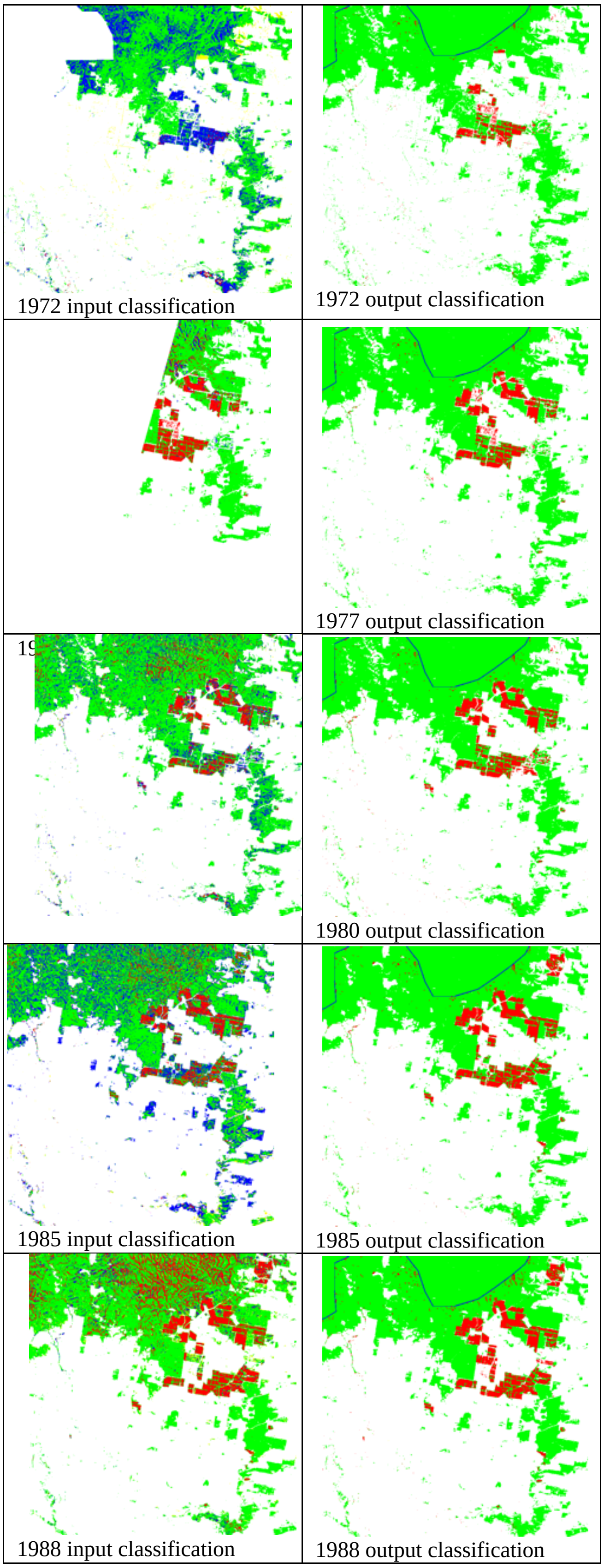
Figure 2: Conditional probability network for pre-1990 plantation type mapping.

The temporal rules were fixed and common to all regions processed. Pilot studies were used to investigate appropriate rules, considering expected rates of change (forest conversion and new plantings) and the relative strength of the temporal and error rates rules. The best results were obtained when the temporal rules were stronger than the error rates (forcing temporal consistency over any individual classification) and when change from native cover to new softwood plantation was considered more likely than conversion from softwood back to native forest. The same temporal rules were used for each interval.

A prior probability was used to weight the classification very slightly towards the softwood class so that regions that are ambiguous throughout the sequence are more likely to be classified as softwood than native.

Spatial / neighbourhood weighting was also applied at this stage in the processing.

Figure 3 shows the input and output classification images for a sample area in the Gippsland region to illustrate the effect of applying the conditional probability network. Areas identified as mixed (ambiguous) in the single-date classifications have been allocated to either softwood or native in the multi-temporal classification as determined by the temporal rules and other classifications. The ‘missing’ data in 1977 has been allocated to a class based primarily on the 1972 and 1980 classifications. The area of softwood plantations is known to have increased over time. The multi-temporal results reflect this expansion in area (i.e. they show the conversion of agricultural land and native forest to softwood plantations). The classification results show an increase from 46000 hectares in 1972 to 64000 hectares in 1988 in the Gippsland region. There is insufficient ground data to make a formal accuracy assessment of the products.



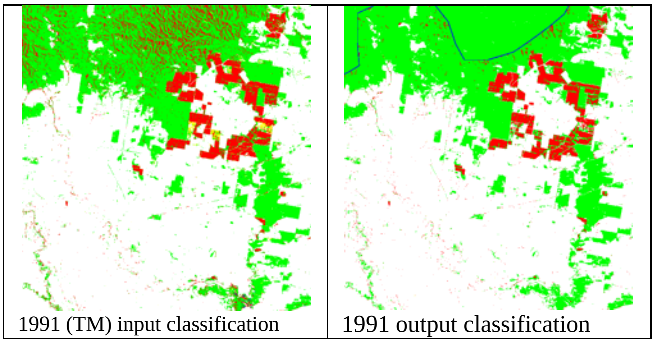


Figure 3: Input (single-date) and output (multi-temporal) classifications for a sample region in the Gippsland region. In the input classifications (four-class) the softwood cover class is shown in red, native in green, mixed in blue and bare in yellow. In the output classifications (two-class) softwood is shown in red and native in green. White in both displays indicates areas not mapped as forest. The blue line in the output displays is the stratification zone boundary. Outside the zone a default classification of native has been applied.

3. SPARSE COVER MONITORING

To meet Australia's current definition of forest, a land cover must have 20% tree crown cover and the potential to reach greater than 2m in height. However, there are large areas of Australia where vegetation communities do not meet this canopy density threshold, in the drier rangeland regions and also within agricultural regions. Increasingly there is a requirement to map and monitor current and historical changes in such areas, at regional and national scales, to provide information for conservation and natural resource management questions. Landsat Thematic Mapper data from 1989 to the present is used. Sparse perennial vegetation cannot be reliably discriminated from other ground cover types based solely on the spectral information in this data; however by including information from image texture the results can be significantly improved (Caccetta and Furby 2004, Furby et al. 2007).

Since it is the texture of sparse perennial woody cover that is of particular interest, the texture is calculated for the 'woodiness' index derived during the forest cover processing rather than for individual image bands. Figure 4 shows a typical texture display with the first two resolutions in the red and green layers respectively and the corresponding image data. Both non-woody regions and forest cover have low texture values (black in the texture display). Sparse cover tends to have mid-range texture values (shades of orange in the display). The highest texture values tend to correspond to edges in the images, such as the bright yellow paddock boundaries in the right half of the texture display.

The speckled nature and one to two pixel shifts observed in the texture images between epochs required some form of smoothing to be applied to the texture images. To achieve smoothing within cover type units while retaining edges which arise from cover type boundaries, a filter based on the Adaptive CMAP algorithm described by McConnell and Oliver (1996) was applied to each texture resolution. The edge preserving properties of the algorithm produced adequate results.

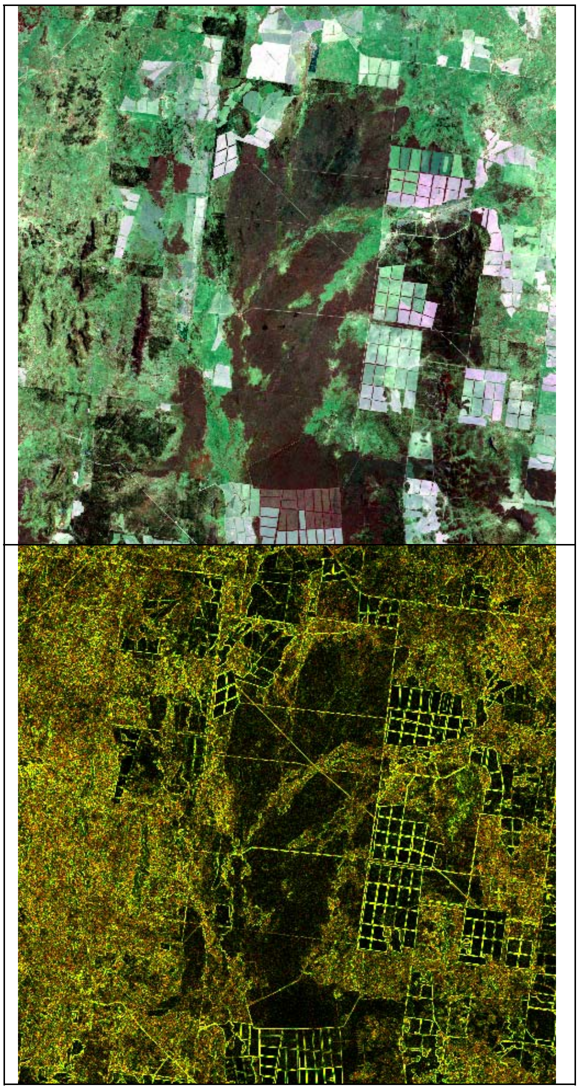


Figure 4: 2002 Landsat ETM+ image (bands 3, 5, 4 in BGR) and corresponding texture display of a region in eastern Australia. The texture display is formed from the first two texture resolutions in the red and green layers. The texture has been calculated from the first forest cover index (the sum of image bands 3 and 5).

The processing is restricted to Landsat TM/ETM+ time slices only (1989 onwards). The spatial resolution of Landsat MSS data is too coarse for there to be a relationship between texture and woody cover density.

The methodology for mapping forest extent and change is extended to include sparse woody cover by combining an index based on the texture measures with the spectral indices at the single-date classification stage. Figure 5 shows the increased discrimination between forest, sparse and non-woody cover when a texture index is included. The multi-temporal classification, again a conditional probability network, is extended to three classes {forest, sparse woody, nonwoody}.

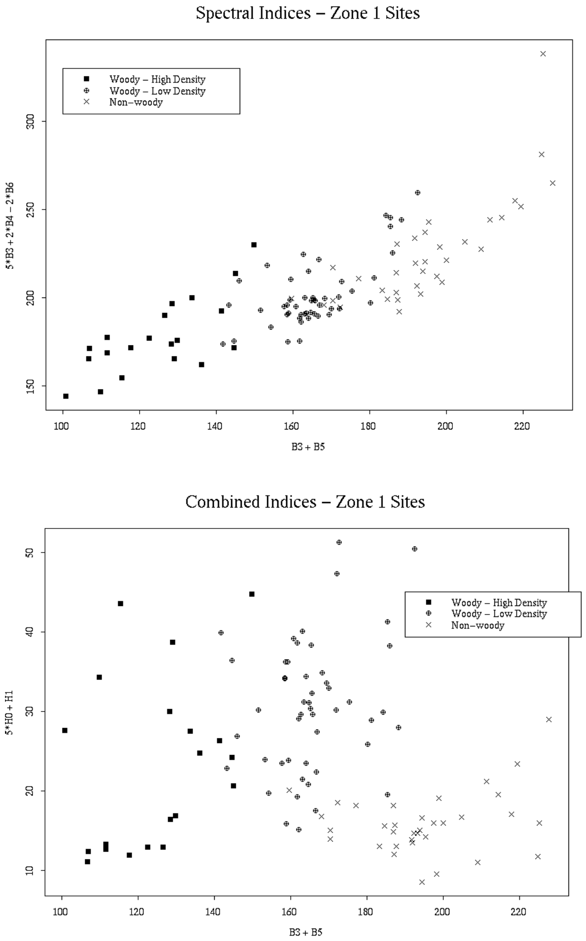


Figure 5: Index plots for a typical stratification zone in eastern Australia. Top: The forest cover (spectral) indices. Bottom: The 'woodiness' spectral index and a texture index.

4. SUMMARY

The ongoing annual forest extent and change and post-1990 Kyoto compliant plantation mapping updates will continue at least throughout the 2008 to 2012 commitment period. The pre-1990 plantation mapping is a one-off activity that is now complete. At the time of writing the methodology for the sparse cover monitoring has been established and tested. Sparse cover 'bases' have been created for a little over half the country and the thresholding processing is ready to be outsourced the to commercial entities.

The Land Cover Change Program has already delivered an archive of consistently processed, multi-temporal satellite imagery and derived land cover products for fifteen nationwide epochs at 25m scale for the 6th largest country (by land area) in the world. The ortho-rectified and calibrated image archive is publicly available as a resource that can be used to help inform a range of natural resource management issues.

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