Pixel-based Image Classification to Map Vegetation Communities using SPOT5 and Landsat TM in a Northern Territory Tropical Savanna, Australia

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Abstract - Traditional techniques to map vegetation communities are by aerial photography interpretation and intensive field sampling. Semi-automated methods, including pixel and object-based image classification, demonstrate potential to accurately map vegetation communities, however, there is a lack of comparative research. This study is a component of a broader research project that compares several techniques and image datasets to map vegetation communities. We evaluated a pixel-based supervised image classification using the Maximum Likelihood Classifier and floristic and structural field data applied to SPOT5 multispectral and Landsat5 TM. The study area covered a subset of Bullo River Station in the Top End of the Northern Territory, Australia. Twenty two vegetation communities were classified based on 411 full floristic and structural plots. Class separability averaged 1.94 and 1.42 for Landsat5 TM and SPOT5 respectively. Overall accuracy ranged from 30-53% for 1:25000 and 1:100000 spatial scale products.

Keywords: accuracy assessment, thematic maps, spatial scale, error matrix, linework, polygon.

1. INTRODUCTION

Vegetation community maps are generated for numerous reasons, such as park management planning, habitat recognition, mine site rehabilitation, update existing surveys, vegetation retention for biodiversity conservation and assist in bioregional mapping, to name a few. This important base line information is used for national and regional monitoring and reporting to support decision making on native vegetation resources.

There are a number of methods to generate vegetation community maps, including aerial photography interpretation (API). This is a traditional method reported to be labour intensive and expensive in terms of image acquisition and pre-processing. Semi-automated techniques using satellite imagery including, pixel and object-based image classification, are also recognised methods. A significant component of vegetation community mapping for all approaches is field sampling. Floristic and structural site data are integral to inform map attribution for API or training areas for supervised image classification.

To improve pixel-based image classification, ancillary data may be used pre or post classification. Ancillary data are any type of spatial or non-spatial information that may be of value in an image classification process. Ancillary data are produced for a specific purpose not intended for remote sensing classification accuracy, therefore the use of ancillary data must be exercised with caution (Jensen 2005). Previous research pertaining to both pixel and object-based classification techniques for vegetation community mapping, have documented the necessity of integrating field and ancillary data with image data to produce more accurate thematic products. Incorporating ancillary datasets in remote sensing image processing systems is reported a straight forward process to assist in vegetation community discrimination (Lees & Ritman 1991; Lewis 1994; Lewis 1998; Lu & Weng 2007; Mehner et al. 2004; Ozesmi & Bauer 2002; Richards et al. 1982; Tunstall et al. 1987).

We present the results of Maximum Likelihood Classification (MLC), a supervised routine applied to SPOT5 and Landsat5 TM multi-spectral data. Two approaches were assessed including an image only and an integrated approach. The image only approach used the image and field data only, whereas the integrated approach used the image and field data and ancillary data such as a Normalised Difference Vegetation Index (NDVI), digital elevation modal (DEM), slope and hydrology layers. Two spatial scale vegetation community maps, 1:25000 and 1:100000, were produced for each approach and a standard accuracy assessment was conducted. The importance of this study is the focus on floristic and structural components of vegetation, which is lacking in other studies across the globe using pixel-based image classification.

This study is a component of a broader research project to compare the accuracy of API, pixel and object-based generated vegetation community maps at two spatial scales. The content covered here are the results of the pixel-based component only. Furthermore, the extent of Bullo River Station was mapped at 1:25000 to satisfy Northern Territory Government requirements using API, however only a subset of the Station was assessed in this paper, referred to as the 'study area' throughout. The study area was selected to minimise processing time for the object-based method, therefore the same study area had to be used for this study. The study area captures the majority of vegetation communities on Bullo River Station and broader tropical savanna region and ensures the highest possible density of site data were included.

2. METHODS

2.1 Study Area

The study area is located on Bullo River Station in the Victoria River District in north western Northern Territory, Australia (Figure 1). The pastoral property covers an area of 1627 km^2 and the study area under assessment includes 530 km^2. The study area is situated in the Bullo River catchment, where three broad landform types are apparent: rugged sandstone hills and escarpment, low hills, rises and plains, and alluvial plains towards the intertidal fringes of the Bullo and Victoria Rivers.

These landform types support a range of habitats typical of northern Australia tropical savannas.

2.2 Field Sampling
The sampling period extended from 2006 to 2009. Three trips were helicopter-based and three vehicle-based. A systematic sampling approach was used to pre-select sites representative of vegetation patterns, and covered the geographic range across Bullo River Station.

Across the Station two site types were sampled, 411 full floristic and 412 less detailed sites (road notes, Figure 1). Full floristic sites were used for the multivariate analysis. Within the study area, 137 full floristic sites and 104 road notes were used in this study. Half of the sites were used to delineate training areas for the supervised image classification, and the remaining half reserved for the accuracy assessment (validation).

For the full floristic sites, all plant species present in a 20x20m quadrat were recorded with associated structural information, including cover, height and growth form within three strata. Refer to Lewis and Fisher (in prep) for comprehensive field sampling methods. Road notes were qualitative and mainly recorded on vehicle-based trips and included dominant species and structural information across up to three strata.

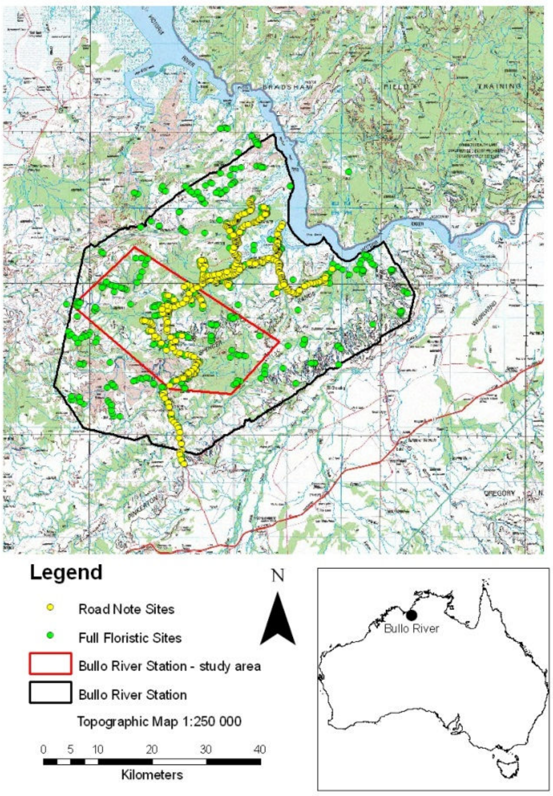

Figure 1. Distribution of full floristic and road note sites across Bullo River Station and the study area.

2.3 Field Data Analysis and Vegetation Classification
Multivariate routines were performed on 392 sites and 957 plant species. A subset of the full floristic dataset was used including the upper strata with species contributing less than 0.1% cover removed and a square root transformation applied, as described by Lewis and Fisher (in prep). The most commonly used similarity coefficient, Bray-Curtis, was conducted and multi-dimensional scaling plots (MDS) used as a visual aid to remove 39 outlier sites to eliminate confusion. Cluster analysis was performed and the dendrogram truncated at an optimal level to produce an acceptable number of floristic groups. A total of 31 vegetation communities for Bullo River Station and 22 across the study area were defined. The number of sites per vegetation community ranged from four to 55.

Vegetation classification was used to summarise vegetation attributes to construct vegetation community descriptions. The classification system used conforms to national standards agreed by the Executive Steering Committee for Australian Vegetation Information (ESCAVI 2003; Hnatiuk et al. 2008). Vegetation communities were described at the National Vegetation Information System (NVIS) Information Hierarchy Level VI - sub-association, the highest level of detail floristically and structurally. Once the vegetation communities were defined, each site for the full floristic and road note dataset were assigned a vegetation community number from one to 31.

2.4 Image Data, Training Areas and Ancillary Data
The SPOT5 and Landsat5 TM scenes were captured in May 2006 and subsequently ortho-rectified. Training areas were manually delineated from the field data. Odd number field sites were input to the image classification and even site numbers reserved for validation. There were two communities (13 & 30) which did not have field sites for the validation, thus additional training areas were selected based on interpreter knowledge of the study area. The areas and number of pixels were comparable for each vegetation community.

Four ancillary datasets were used in the integrated approach of this study including, NDVI, DEM, slope model, and the 1:250000 hydrology layer. The NDVI, NIR-Red/NIR+Red, was calculated for Landsat5 TM and SPOT5 multi-spectral scenes. The DEM was acquired through the Australian Defence Force as a 30x30m post spacing, 10m contour file (currency 1990-1994). From the DEM a slope model was generated. The hydrology layer was used as a surrogate for two community training areas in the integrated approach and included major rivers and creeks buffered at 80m (community 21) and minor creeks at 30m (community 4). These image datasets were subset to the study area boundary.

2.5 Supervised Image Classification
Two methods were applied. An Image only approach (image data & field data training areas), and an integrated approach (image data, field data training areas & ancillary data – NDVI, DEM, slope model & hydrology).

Image-only Approach
Class separability of the training areas were computed. A supervised MLC was conducted. The classification results were smoothed using a majority filter (3x3 kernel). Two vegetation community maps were generated at 1:25000 and 1:100000 spatial scale where polygons less than 0.04 and 0.25 hectares respectively were eliminated. Manual class mapping of the 22 communities was conducted on the four resultant maps prior to accuracy assessment.

Integrated Approach
For both the Landsat5 TM and SPOT5 datasets, five combinations of ancillary data were assessed: 1. DEM only, 2. DEM and NDVI, 3. DEM and slope, 4. DEM, slope and NDVI, and 5. DEM, slope and hydrology. Combining the datasets involved layer stacking with the exception of the hydrology

dataset. The hydrology dataset was used in the image classification process by replacing the field data training areas for communities 4 and 21. Supervised MLC was applied to the five combinations of layer stacked datasets for Landsat5 TM and SPOT5 as per the image only approach. Post-processing included the majority filter (3x3) and eliminating polygons to derive the two spatial scale maps for the integrated dataset that gave the highest overall accuracy.

2.6 Accuracy Assessment

Fourteen confusion matrices were calculated for the classification datasets generated for the image only approach and all combinations of the integrated approach, including the two spatial scales. The training areas reserved for the accuracy assessment were used to match with the classes in the classified image. Overall accuracy, kappa coefficient, omission and commission and producer and user accuracies were computed and results analysed for the image only Landsat5 TM and SPOT5 spatial scale maps and the highest accuracy result for the integrated approach.

3. RESULTS AND DISCUSSION

3.1 Supervised Image Classification

The average class separability was superior for Landsat5 TM when compared to SPOT5 and incorporating the DEM and slope data improved class separability for both image datasets (Figure 2).

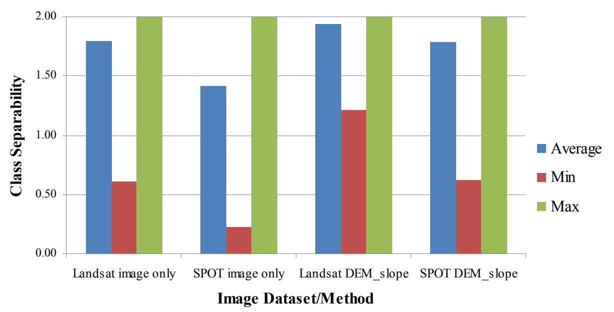

Figure 2. Range and average class separability for the Landsat5 TM and SPOT5 image only and integrated Landsat5 TM_DEM_slope and SPOT5_DEM_slope classifications.

Twenty two vegetation communities were described across the study area. Appendix 1 outlines brief community descriptions and Appendix 2 illustrates the maps at the two spatial scales. Refer to Lewis and Fisher (in prep) and Lewis and Phinn (in prep) for full vegetation community descriptions.

The most common and widespread vegetation community was 1 and occurred across a range of landform patterns and substrates, the most extensive being on plains and rises and hill slopes of low hills and hills. Another vegetation community that intergraded on the plains, on imperfectly drained soils typically adjacent to water courses, was community 7. The class separability for these communities was one of the lowest for both Landsat5 TM and SPOT5 (0.86 & 0.52 respectively for the image only approach). This was reflected in the classification results for the image only and all combinations of the integrated approach.

Community 2 was widespread on a range of sandstone landform patterns and well classified in both approaches and image datasets. Although some misclassification resulted due to exposed sand in the riparian community, the incorporation of the hydrology layer overcame this. Community 22 was also extensive and characteristic of broken sandstone plateaus and hills. From visual interpretation all fire scars on both image datasets were classified as this community. Misclassification was apparent with other communities such as 12 and 2 due the similar spectral characteristics which was evident in the class separability computations.

Community 10 was another widespread community generally in association with community 22 and 2, although had higher cover in the upper strata. These communities appeared to be acceptably classified for both methods and image datasets. Community 6 existed as three forms, an influence of substrate and landform. A typical form was on the plateaus, a second form occurred on rugged sandstone hill slopes and the third was on heavier soils adjacent to drainage lines on the alluvial plains. Due to these variations, this community appeared quite confused, however still managed to classify pixels for the plateau and alluvial plain associations.

The major river system (Bullo River) and its perennial tributaries were dominated by community 21, also including significant paperbark swamps. The second riparian community were ephemeral stream channels across plains, rises, low hills, hills and plateaus, usually in association with community 21. Combining the DEM and NDVI improved the results for riparian communities from the image only approach, however misclassification still occurred. Combining the hydrology layers improved the results again, however resulted in misclassifications elsewhere, particularly community 4 being classified as shadow on the hill slopes and on exposed sandstone across community 22.

Other swamps were dominated by either tussock grasses or sedges and included communities 8 and 30 respectively. Community 30 had misclassified pixels in shadowed areas using the image only approach. The incorporation of a DEM and NDVI improves the result where shadow was no longer classified; however, the use of the NDVI layer caused this community to be misclassified as riparian communities, especially in the Bullo River gorge system. The introduction of the slope model with DEM and removal of the NDVI improved the result. The most superior combination of ancillary datasets for riparian and swamp communities is the integration of the DEM, slope model and hydrology layer. The grassland community was not extensive and only occurred in a few locations on black soil plains.

On the drainage depressions, communities 11 and 20 were either discrete or intergraded. These communities were dominated by either *Corymbia polycarpa* or *Melaleuca viridiflora* and were usually adjacent to the relict levees of the Bullo River and its tributaries. There was some confusion between the two, due to low class separability, although overall adequately classified the drainage depressions. Adjacent to drainage depressions and major riparian systems were relict levees dominated by community 3 and neighbouring on the plains was community 18. Community 5 was also common on the levee systems as well as plains, however not as extensive as the later. These three communities were classified well.

Community 12 dominated slopes in the image only approach which was misclassified as community 30 due to shadow effect. The classification results were improved with the incorporation of the DEM and further with the slope model. Also common on scarps and the heads of gullies on plateaus, escarpments and hills was community 28, dry vine thicket. There was confusion with the image only approach where many riparian areas were misclassified as community 28. The incorporation of the NDVI and DEM reduced this confusion, with the DEM, slope and hydrology integration also giving similar results. The slope model is integral to improving classification results for communities that have a high slope.

A less extensive community that occurred on hills and plateaus, in pockets on permanent springs, was 13, all classification results depicted this reasonably well. Confined to the hills in the north-west corner of the study area on a distinctive geological type were communities 15 and 16 and were under-classified possibly due to the small number of training areas and communities such as 12 being spectrally similar. The incorporation of the slope model did not improve this, as they all occurred in elevated areas with high slope.

Overall, the class separability was improved significantly when the DEM and slope model were incorporated for both image datasets (Figure 2). The spectral information of the Landsat sensor compensated for its coarser spatial resolution. The SPOT5 high spatial resolution was the result of misclassification's, especially with sparsely vegetation communities with bare ground existing between tree canopies. This premise was also apparent in similar studies that compare SPOT and Landsat TM for vegetation community mapping.

3.2 Accuracy Assessment

The results of the image only and integrated approaches indicate that the incorporation of ancillary data considerably improved overall classification results. Figure 3 illustrates that the incorporation of a DEM and slope model improves classification results for both image datasets. Despite the NDVI improving classification results in areas that were highly vegetated, namely on the alluvial plains, it confused the classification across extensive areas which were exposed and sparsely vegetated. Similarly, the incorporation of the hydrology layer as training areas for two riparian communities improved the results noticeably for these classes, however created confusion elsewhere.

The vegetation communities that were misclassified in the image only approach included those confined to sedgeland swamps (30), dry vine thicket (28) restricted to scarps and steep gully heads, the riparian communities (4 & 21), spring fed community (13) and a very mixed community occurring on hill slopes (12) extensively across the study area. These communities were often misclassified as a result of shadow on the steep slopes, in gorge systems and water bodies.

The incorporation of the DEM and slope model removed the majority of the above errors. However, in areas with little topography, errors were still apparent. These included communities on alluvial plains, low in elevation and slope. Pixel-based image classification fails to depict the floristic detail of vegetation communities which is supported by numerous studies across the globe.

On the whole, any combination of image and ancillary dataset was superior to the image only approach applied to Landsat5 TM and SPOT5. The dataset demonstrating the highest overall accuracy and kappa was the Landsat5 TM with DEM and slope integrated at 1:25000 (Figure 3). The incorporation of the DEM and slope model improved the classification of the image only approach by 10%.

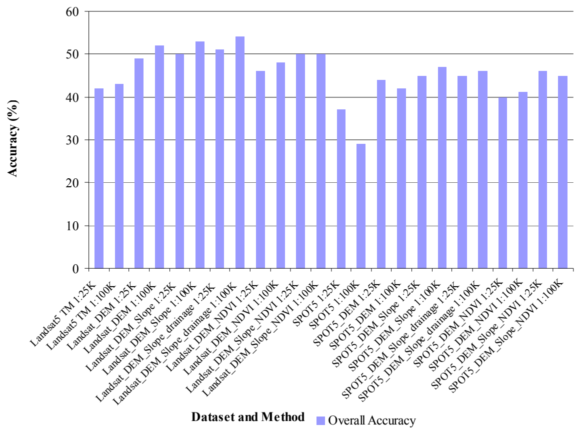

Figure 3. Overall accuracy for the image only approach and all combinations of the integrated approach, for 1:25000 and 1:100000 spatial scales.

We evaluated the best classification results for the image only approach (Landsat5 TM) and integrated approach (Landsat5 TM integrated with DEM & slope model) for the 1:25000 maps. The producer and user accuracies indicate overall, the producer accuracy on average (40%) was higher for the image only classification and a marginal difference for user accuracy (5%). For the integrated approach producer and user accuracies were 34% and 35% respectively.

3.3 Spatial Scale Comparison

There was a general trend in increased overall accuracy when the original classifications were generated as 1:25000 and 1:100000 products (Figure 3). The exception was with the SPOT5 1:100000 image only product where the accuracy decreased dramatically. When smaller polygons were eliminated, the map seemed to lose context. Appendix 2 illustrates four thematic maps produced from supervised image classification for the highest overall accuracy integrated approach for Landsat5 TM and SPOT5. The maps provide a visual representation of the attribute and spatial detail eliminated between the 1:25000 and 1:100000 maps. This result surmises the need for finer spatial scale maps for property management planning and courser scales more appropriate for regional applications.

4. CONCLUSIONS

The results of the image only and integrated approaches indicate that the incorporation of ancillary data considerably improved overall classification results. The amalgamation of a DEM and slope model with Landsat5 TM was superior to any other combination of image and ancillary data for this study area, which is topographically variable. In this study area, despite the NDVI improving classification results in areas that were highly vegetated, it confused the classification across extensive areas which were exposed or sparsely vegetated. Similarly, the incorporation of the hydrology layer as training areas for two riparian communities, improved the results noticeably for these classes, however created confusion elsewhere. The use of ancillary data must therefore be carefully evaluated for a particular study area and associated environmental conditions. For other regions which do not have such variability, other combinations of ancillary, image and field data may be more suitable.

Landsat5 TM was superior to the SPOT5 imagery, despite the higher spatial resolution of SPOT5. Presumably, Landsat's additional spectral information compensates for the coarser spatial resolution. Spatial scale, or mapping scale, has an influence on attribute and spatial information continued in thematic maps. The amount of detail lost between the 1:25000 and 1:100000 spatial scale maps was significant and substantiates the requirement for finer spatial scale mapping (i.e. 1:25000) for property management and 1:100000 is acceptable for regional applications.

Suggestions to improve this work include the use of a fuzzy accuracy assessment to compensate for continuous variables like vegetation communities. The application of fuzzy rules to this study would strengthen the results of vegetation communities with poor separability and similar landscape position. Despite the hydrology layer being used as training areas for the image classification in the integrated approach, an acceptable means may simply be to mask the two riparian communities from the classification and label the masks accordingly.

WorldView-2 imagery, comparable in the number of spectral bands to Lands5 TM and a much higher spatial resolution to SPOT5 (8-band multispectral & a spatial resolution of 46cm), would be of interest in this study region and expected to yield better accuracy results.

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APPENDICES

Appendix 1. Twenty two diagnostic vegetation community descriptions.

ID	Diagnostic Community Description
1	*Eucalyptus tectifica* Low Woodland
2	*Corymbia dichromophloia* Medium Low Open Woodland
3	*Corymbia bella* Mid Woodland
4	*Lophostemon grandiflorus* Mid Woodland
5	*Eucalyptus pruinosa* Low Open Woodland
6	*Eucalyptus miniata* Mid Open Woodland
7	*Corymbia grandifolia* Mid Open Woodland
8	Mixed species Mid Tussock grassland
10	*Eucalyptus phoenicea* Low Open Woodland
11	*Corymbia polycarpa* Mid Open Woodland
12	Mixed species Low Open Woodland
13	*Corymbia ptychocarpa* Mid Woodland
15	*Eucalyptus brevifolia* Low Open Woodland
16	*Melaleuca sericea* Low Open Woodland
17	*Corymbia ferruginea* Low Open Woodland
18	*Corymbia foelscheana* Mid Woodland
19	*Melaleuca minutifolia* Low Woodland
20	*Melaleuca viridiflora* Low Woodland
21	*Melaleuca leucadendra* Mid Woodland
22	Mixed species Tall Sparse Shrubland
28	Dry vine thicket mixed species Mid Woodland
30	Mixed species Low Closed Sedgeland

Appendix 2. Four maps illustrating the level of attribute and spatial detail for Landsat5 TM and SPOT5 at 1:25000 and 1:100000 spatial scales. The maps are derived from the integrated approach where the DEM and slope model were incorporated in the supervised image classification.