Abstract

The production of a preliminary land cover map by spatial analysis, which integrates remotely sensed imagery with GIS, may provide a useful tool in the selection of sites for vegetation mapping and other natural resource inventory surveys. eCognition, an object-oriented image analysis software package, was used to produce a preliminary land cover map of Groote Eylandt with 20 land cover classes prior to the commencement of vegetation surveys. Spectral bands from satellite imagery were used as a basis for segmentation, and classification was performed using combinations of spectral bands, slope, elevation, radiometric data and the application of semantic rules, fuzzy logic and manual classification. Botanists were then able to use the land cover map to guide site selection for vegetation assessment and mapping of the island. Feedback from botanists suggests that a preliminary map produced prior to field work and assessed in the field enables the accuracy to be improved. For the Groote Eylandt project this was particularly important for the land cover class “swamp” which, when ground truthed, was found to comprise three vegetation types. The production of a preliminary land cover map is the first step in an iterative process and the information collected by botanists can now be used to create a map informed by ground survey data.
Introduction

Vegetation surveys provide the basic information for land cover and other forms of environmental mapping. Traditionally, the *a priori* selection of survey sites is generally based on topographic and geologic maps and is augmented in the field by opportunistic sampling. To produce meaningful land cover classification and mapping it is necessary to adequately sample each land cover class. Although botanists routinely use remotely sensed imagery in site selection, the framework provided by a preliminary land cover map may improve the efficiency and comprehensiveness of sampling. Access in the field to a preliminary land cover map based on remotely sensed and GIS data layers also provides an opportunity to ground truth the classification.

Study Site

Groote Eylandt is Australia’s third largest island (2258 km²), and the largest in the Gulf of Carpentaria. The island is situated approximately 50 km off the eastern coast of Arnhem Land, east of Walker River and south-east of Blue Mud Bay (Figure 1). The Traditional Owners are the Anindilyakwa people and there are a number of communities on the island. A large manganese ore deposit in the western portion of Groote Eylandt is mined by GEMCO (Groote Eylandt Mining Co Pty Ltd). There has been relatively little environmental sampling for Groote Eylandt prior to this survey, and, apart from the area around the mine, no previous vegetation or land unit mapping.

![Figure 1. Location of Groote Eylandt off the coast of the Northern Territory, Australia.](image)
Overview of eCognition

ECognition was used in this project to segment and classify land cover classes on Groote Eylandt. ECognition is able to utilise size, shape, colour and contextual information in the classification process, and provides a way to integrate remotely sensed data and GIS (Benz et al 2004). An overview of the procedures performed by ECognition are presented in Figure 2.

Software packages routinely used to classify imagery classify individual pixels. In contrast, ECognition first segments the image into patches (or polygons), which are referred to as “object-primitives” in the ECognition manual. These object-primitives are “internally homogenous”, that is, the variance within an object-primitive is smaller than the variance between object-primitives (Flanders et al 2003). The user is able to set the level of internal homogeneity of the object-primitives produced. Segmentation using ECognition can be based on spectral information, such as the ratio between bands and different combination of bands. Unlike routinely used software, ECognition can incorporate other spatial data layers such as geology, elevation, slope and radiometric measurements into the segmentation procedure.

ECognition can use fuzzy logic to classify the object-primitives generated by the segmentation algorithm. Training areas are selected to represent particular land cover classes and the user defines which layers the algorithm uses as the basis for classification. For example combinations of landsat bands, NDVI (Normalized Difference Vegetation Index), slope, elevation or radiometric counts can be selected and define how ECognition sorts each object-primitive into a class. Each object-primitive classified based on the training areas is assigned a “possibility” of membership to the three most “possible” classes. This “possibility” is represented as a number between zero and one, but it is not necessary that the sum of the three possibility scores equals one, that is, the possibility scores do not follow the rules of constrained probability. The possibility of belonging to more than one class is a characteristic of fuzzy logic.

Objects can also be classified using Boolean logic (or hard classifiers) where an object-primitive may belong to only one class. Semantic rules (which follow Boolean logic) can be incorporated, for example all object-primitives with a landsat band value below a defined level are assigned to a particular class. This enables the incorporation of user knowledge. These semantic rules can be nested to form a hierarchy of decisions. ECognition also enables the grouping of classes split by earlier decisions, and object-primitives can also be manually attributed.
eCognition allows segmentation to be performed at multiple scales, and the spatial relationship between object-primitives created at different scales can be used during classification. An examination of the relationships between object-primitives created at different scales can capture spatial concepts such as neighbourhood, proximity or homogeneity (Burnett and Blaschke 2003), and enables the classification of objects based on their relationship with collocated or adjacent upper level objects (Flanders et al 2003). Burnett and Blaschke (2003) refer to this as object relationship modelling or hierarchical patch dynamics (HPD). This was not addressed by the present study.
Methodology and Results

Data Layers Used
A number of data layers were used as a basis of segmentation and classification of Groote Eylandt as listed below.

- Satellite Imagery
  Two Landsat TM 7 scenes (Path/Row 102/70 and 102/69) acquired in the early dry season of 2000 were calibrated and mosaiced to form an image covering Groote Eylandt. The scenes were supplied by the Australian Greenhouse Office (AGO). Readers interested in the processing routinely performed on AGO imagery are encouraged to contact the AGO. The image is in datum GDA94, projection MGA53.

Early dry season imagery was used to avoid the confounding effects of fire scars, although there were several small areas that had been burnt. Unfortunately there was some scattered cloud over Bickerton Island to the north-west of Groote Eylandt, making accurate mapping difficult in that area.

- Digital Elevation Data
  A Digital Elevation Model (DEM) (scale 1:100 000, resolution 100 m) produced by the Department of Infrastructure Planning and Environment of the N.T. (DIPE), was used to derive elevation and slope for the island.

- Geology
  Four 1:250 000 scale geology map sheets (map sheets SD 5307, SD 5308, SD 5311, SD 5312) were mosaiced together then reclassified into seven broader categories: basalt, laterite, coastal sand, gravel and sand, black soil, sandstone and quartzite sandstone.

- Airborne Radiometric Data
  Gamma-rays emitted by rock and soils can be remotely sensed from aircraft. The Northern Territory Geological Survey produced a radiometric map covering most of the N.T., including Groote Eylandt, using airborne data collected between 1974 and 2002.

Radiometrics refer to the intensity of gamma-rays emitted from the ground surface and corresponds to levels of mineralization in the top 30-45cm of dry rock or soil (Gregory and Horwood 1961). As weathering processes redistribute radioelements from the bedrock source, radiometric measurements can relate more closely to soil mineralization than the geology of the bed rock (Wilford, Bierwirth and Craig 1997). This enables the mineralization of soils to be mapped. As soils (and mineralization) influence plant communities, radiometric data have been used in vegetation mapping in the Northern Territory (Hempel 2004).

For the Groote Eylandt project, three radiometric measures were used: potassium, thorium, and a total count which represents combined
measurements of these two elements plus uranium (Figure 3). As summarised from Wilford, Bierwirth and Craig 1997: sand has a very low total count (close to zero), sandstone is generally low, and laterite, ferricrete, and volcanics (basalts, granites) are highly mineralized and have correspondingly high total counts. Potassium occurs in K-feldspars and micas, and is low in mafic rocks. Traces of thorium and uranium are found in feldspars and their concentrations increase with rock acidity, that is, in rocks high in silica.

![Image A](image_A.png)  ![Image B](image_B.png)

Figure 3. (A) Radiometric total count, and (B) Radiometric measurements of potassium for Groote Eylandt.

**Image Segmentation**

Landsat TM bands 1 to 5 and 7 were used in eCognition’s segmentation process and were evenly weighted. The image was segmented with a constant “composition of homogeneity criterion” and the “scale parameter” set at three levels: 10, 20 and 50. The scale parameter and the composition of homogeneity criterion define a threshold for the maximum change in heterogeneity that may occur when two object-primitives are merged, and any merging that exceeds the defined level terminates the segmentation process. A larger scale parameter results in a smaller number of object-primitives (Table 1). The default settings for the “composition of homogeneity criterion” were used, that is colour 0.9, shape factor 0.1, with shape factor divided into compactness 0.5, smoothness 0.5. Figure 4 shows the segmentation produced by eCognition for an area of sandstone on Groote Eylandt.
Table 1. Three segmentation layers defined by scale parameter settings and the number of object-primitives produced at each segmentation scale.

<table>
<thead>
<tr>
<th>Level</th>
<th>Scale parameter</th>
<th>Number of object-primitives (polygons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>54181</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>15838</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td>3291</td>
</tr>
</tbody>
</table>

A. B.

Figure 4. (A) Satellite image of sandstone on Groote Eylandt, and (B) Segmentation of satellite image using eCognition.

Semantic Rules
Semantic rules were used as the first step in the classification process and object-primitives may only belong to one class.

- First division: The object-primitives were classified into “water” or “terrestrial” by using Landsat band 4 (infrared) which is absorbed by deep water and therefore returns a very low value. The semantic rule was: Band 4 < 35 = water, band 4 > 35 = not water.
• Second division: Within the “terrestrial” group of object-primitives radiometric total count was used to classify objects into “sand” (total count < 30) and “mineralised” (total count > 30).

• Third division: Within “mineralised”, radiometric total count was used to classify objects into “laterite” (total count > 110) and “sandstone” (radiometric total count < 110). Note that the class “sandstone” really refers to an area with an intermediate level of mineralisation. It does not represent areas of pure sandstone, and swamps and mangroves occur in areas classified as “sandstone”.

These hierarchical semantic rules produced four classes: deep water, sand, sandstone and laterite, as shown in Figure 5.

Figure 5. Groote Eylandt classified into deep water (black) and areas of sand, sandstone and laterite. Fire scars are shown as hollow black polygons.
Fuzzy Logic
The terrestrial classes were further subdivided by selecting training sites and performing a supervised classification. The image layers used to define the “nearest-neighbour feature space” were customised for sand, sandstone and laterite (Table 2). For example, for the classification of object-primitives within the sand class, Landsat bands 3, 4, 5, 7 and NDVI were used to define the nearest-neighbour feature space, and the mean of these data layers for each object-primitive was used as a basis for classification.

<table>
<thead>
<tr>
<th>Data Layers</th>
<th>Sand</th>
<th>Sandstone</th>
<th>Laterite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat band 3</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Landsat band 4</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Landsat band 5</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Landsat band 7</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>NDVI</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slope</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Elevation</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Radiometric total count</td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

Training areas were selected from the finest scale segmentation output (level 1) and several iterations of training area selection and classification were run to produce a meaningful set of land cover classes. This classification algorithm was then applied to two coarser scale segmentation output layers.

Radiometrics
High radiometric total counts were used to classify object-primitives into “Laterite”, but within the classes of laterite and sandstone some areas of high potassium were evident. One area in the north of the island shows a ridge of potassium rich soil or rock, and an area where high potassium substrate has eroded and been redeposited fluvially (Figure 6). A second area in the east of Groote Eylandt seems to be potassium rich quartzite in a folded band of sparsely vegetated rock (Figure 6). Although the radiometric data indicate interesting soil characteristics in these two areas, whether this is reflected in an unusual vegetation type will not be known until after analysis of the field data.
Figure 6. Fluvial deposition of potassium rich sediment in northern Groote Eylandt. (A) Satellite image of the area, (B) Radiometric potassium showing erosion and deposition of potassium rich sediment, (C) Overlay of satellite image and radiometric potassium showing how the high potassium sediment has been deposited along the drainage line.

Figure 7. Segmentation and classification of areas with high radiometric potassium in eastern Groote Eylandt. (A) Satellite image of folded quartzite, (B) Radiometric measurement of potassium in folded quartzite rock, (C) Overlay of satellite image, radiometric potassium and segmentation performed by eCognition.

Manual Attribution
Some object-primitives were manually attributed, for example the areas around the mine have a signature similar to burnt areas and were manually attributed to the class “built up area”. Likewise, some object-primitives were manually assigned to either swamp or mangrove. The classification hierarchy is shown in Figure 8.
After segmentation and classification, several classes were similar, but had been generated separately as the first set of semantic rules classified the island into three broad geology types. For example the sand, sandstone and laterite classes all contained object-primitives classified as “fire scars”, and these were aggregated to form a single class called “fire scars” (Figure 3).

Other classes aggregated were:
- dunes on sandstone and on sand
- swamp on sand, sandstone and laterite
- closed forest on laterite and coastal thicket on sand
- high potassium areas in laterite woodland, in the laterite fire scars class, sandstone pavement and in sandstone woodland

The final land cover classes used for the mapping of Groote Eylandt are shown in Table 3.

### Table 3. Land cover classes for Groote Eylandt.

<table>
<thead>
<tr>
<th></th>
<th>Sand</th>
<th>Sandstone</th>
<th>Laterite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep water</td>
<td>Woodland on sand</td>
<td>Sandstone woodland</td>
<td>Laterite woodland</td>
</tr>
<tr>
<td>Turbid water</td>
<td>Open forest on sand</td>
<td>Sandstone open woodland</td>
<td>Laterite open woodland</td>
</tr>
<tr>
<td>Open</td>
<td>Coastal heath</td>
<td>Sandstone pavement</td>
<td>Potassium rich woodland</td>
</tr>
<tr>
<td>Fire scar</td>
<td>Dune complex</td>
<td>Quartzite pavement</td>
<td></td>
</tr>
<tr>
<td>Mangrove</td>
<td>Closed forest on sand</td>
<td>Sandstone cliff</td>
<td></td>
</tr>
<tr>
<td>Swamp</td>
<td></td>
<td>Forested gorge</td>
<td></td>
</tr>
</tbody>
</table>

### Exporting eCognition output to other software packages

The output from eCognition can be exported and each object-primitive, now referred to as a polygon, can be exported with a suite of information unique to that polygon. eCognition’s classification output automatically provides the possibility of membership to the three most likely classes, and the user is able to select additional attributes. The following were selected for the Groote Eylandt project, all calculated as the mean for each polygon: NDVI, Landsat bands 3 to 5 and 7, elevation, slope, radiometric total count, radiometric potassium and thorium. After exporting the data, ArcMap was used to create several map documents with total count and potassium radiometrics, geology, and the polygons classified into 20 land cover classes (Figure 9).
Discussion

The map of land cover classes of Groote Eylandt was used by Biodiversity Conservation botanists to select sites for a vegetation survey of the island. The production of this map is the first step in an iterative process and the information collected by botanists can now be used to feed into the second round of classification to improve mapping accuracy. Elements identified by Biodiversity Conservation botanists Jenni Risler (J.R.) and Ian Cowie (I.C.) as useful or in need of refinement are summarized below. Feedback was guided by the following questions: Was the preliminary land cover map of Groote Eylandt useful to botanists during site selection for vegetation survey? and, Did you find the radiometric layers (total count, potassium and thorium) useful?

Site Selection
Both botanists were of the view that although the preliminary land cover map was a useful tool for site selection, it would always be used in conjunction with topographic, satellite imagery, geology and radiometric data by botanists. J.R. noted that the electronic version of the map taken into the field on a laptop was a most useful tool, as areas of interest could be examined at a finer scale than on the hard copy of the map, and other data layers could also be accessed.
Remotely sensed data, such as the satellite image and the radiometric data effectively showed landscape scale patterns, but could not always be used to identify small areas of unusual vegetation. Sampling methodology needs to retain the flexibility to enable the survey of fine scale or subtle floristic variation.

Radiometrics
The radiometric layers were identified as a useful tool to examine the variation in soil or surface rock characteristics. I.C. found that laterite, identified from the radiometric total count layer corresponded in the field to 20-30cm deep laterite gravel. The rare orchid, *Calochilus holtzei*, was recorded on Groote Eylandt by I.C., J.R. and Kym Brennan during field work for this project, and it had previously been collected from a similar substrate on Cobourg Peninsula. Field observations by I.C. show that the area of high potassium identified from the radiometric data (shown in figure 6) was characterised by soils with a higher clay content. The only population of *Eucalyptus jensenii* on the island was located in the vicinity of the high potassium substrate. These two examples may demonstrate the usefulness of the radiometric layers in surveys targeting specific plant species or vegetation types, if they are known to be associated with particular substrates.

Ground truthing the map
Ground truthing the classification of land cover classes may enable a more accurate map to be created. J.R. observed that the class mapped as “swamp” corresponded to three vegetation types on Groote Eylandt. During our classification of object-primitives, “swamp” was created as an aggregated class and combines swamp on sand, sandstone and laterite. These classes can be separated out by changing the “grouping” in eCognition. Regardless of the primary substrate, however, some of these areas classified as swamp were found to be coastal vine thicket, and the classification procedures need refining to accurately classify these vegetation types. In contrast, some of the woodland categories were thought by I.C. to be structurally and floristically similar. The final land cover map would aggregate these classes into one vegetation type.

Conclusion
The methodology applied here using eCognition produced a useful land cover map with 20 land cover classes. The software has the flexibility to use non-spectral layers and user knowledge during the segmentation and classification process. Systematically developed guidelines for the use of eCognition in classification of vegetated areas into land cover classes would be most useful.

The preliminary land cover map was useful to botanists in site selection for a vegetation survey of Groote Eylandt and was used in conjunction with radiometric, topographic, geologic layers and satellite imagery. The opportunity to validate the preliminary land cover map is expected to lead to a more accurate map of the vegetation communities on Groote Eylandt. Radiometric data was used to identify landscape scale variation in soil characteristics, which
in some areas was reflected in floristic variation. The project demonstrated the usefulness of object-oriented preliminary land cover mapping in providing a tool to guide vegetation surveys.

Acknowledgements

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References


