Use of airborne thematic mapper (ATM) to map the distribution of blackberry (*Rubus fruticosus* agg.) (Rosaceae) in the Strzelecki Ranges, south Gippsland, Victoria.

E. Ullah, R.P. Field*, D.A. McLaren*, and J.A. Peterson.

Monash University, Department of Geography and Environmental Science, Clayton, Victoria 3168, Australia

*Keith Turnbull Research Institute, Department of Conservation, Forests and Lands, P.O. Box 48, Frankston, Victoria 3199, Australia.

Summary

A multispectral airborne thematic mapper was used to obtain digital imagery of blackberry (*Rubus fruticosus* agg.) infestations in the south Gippsland area. Distribution patterns obtained by image data enhancement and transformation were verified in the field and by comparison with verified air photographs previously taken for the Blackberry Biological Control Program. Field verification was possible in considerable detail because of the high spatial and spectral resolution offered by ATM data. The phase of the program reported here did not involve attempts to differentiate between blackberry species, or between healthy specimens and those affected by the biological control agents, such as the rust fungi *Phragmidium violaceum* (Schultz). Nevertheless, results demonstrate that the methods used would be effective for detailed monitoring of blackberry distribution patterns if time series ATM data was acquired. Such monitoring would be important, not only as part of control programs but also for assembling information that may be required to resolve conflicts of interest, or to determine rates of compensation (e.g. see Delfosse 1985, Field and Bruzzese 1985).

Introduction

Reliable estimates of the distribution and density of weed infestations over wide expanses of land are useful in determining the environmental impact and dynamics of weed species. While weed survey methods should be chosen according to survey objective (Pitt and Miller 1988), remote sensing has long been recognized as offering the means of obtaining accurate and effective distribution patterns over large areas of moderate to dense infestation (e.g. see Cuthbertson 1978). The nature of distribution patterns differ from weed to weed; some, like blackberry, tending to be best established in scattered clumps or along creek edges, while well established infestations of others, like Paterson's Curse (*Echium plantagineum* L.) will present uniform cover over tens of hectares. Accordingly, the spatial resolution required for remote sensing will vary. Our data acquisition flight was planned to yield pixel sizes of 5 m x 5 m, with some areas being covered with a spatial resolution of 2.5 m x 2.5 m, over the Calligne South area (Figure 1) already studied as part of Keith Turnbull Research Institute (KTRI) research work aimed at establishing biological control of certain weeds. The biological control experiments for blackberry started some twelve years ago and several virulent strains of a rust *Phragmidium violaceum* (Schultz) Winter (Uredinales) are currently being reviewed for release as control agents.

Illegal release of a low virulence strain of this rust in 1984 has resulted in rapid spread (Bruzzese and Field, 1985). It is now found throughout southeastern Australia where it attacks many but not all species in the *R. fruticosus* aggregate (Bruzzese, pers. comm.). There is added incentive, therefore, to identify the spectral characteristics of blackberry in its vigorous and its rust-affected states so that the impact of the low virulence strain of *P. violaceum* on the various blackberry species can be assessed as part of an evaluation of options for future blackberry control programs. This project established a method for mapping blackberry distribution in a way that could be developed for more detailed mapping in connection with the biological control work.

Remote Sensing

Remote sensing is the gathering of spatial information from a distance. Techniques used include conventional and false colour infra-red photography, and multispectral scanning, either from aircraft or satellite platforms.

Photography has been used for vegetation mapping for over a century (Anon 1887), and, although capable of providing spatial detail and geometric integrity to a high degree (Lillsand and Kiefer 1979), is limited to the visible and near infra-red parts of the electromagnetic spectrum. In addition, the utility of photographs is constrained by the nature of analogue modelling (which needs interpretation of a kind that must vary somewhat from one interpreter to another) and the need for comprehensive photogrammetric control if large areas are to be covered, because many separate models (photographs or stereo pairs of photographs) must be planimetrically linked. Aerial photography was used in this study (Figure 2) to document biological monitoring sites, and in the preliminary test of spectral data (Field, McLaren, Baxter and Hill 1989) and in ground verification ("truthing") activities.

The multispectral scanner (MSS) used in this study was a Daedalus DS 1268 ATM recording 11 data channels (Table 1). MSS

Table 1. Daedalus Airborne Thematic Mapper Radiometric Characteristic (Tian 1987)

Bands of DATM	Wavelength (micrometre) TM bands	Equivalent Landsat 4,5	Basic Properties for Vegetation
1	0.42 - 0.45		Sensitivity to chlorophyll and carotenoid concentration
2	0.45 - 0.52	1	Sensitivity to chlorophyll and carotenoid concentration
3	0.52 - 0.60	2	Slight sensitivity to chlorophyll and green reflectance by green vegetation
4	0.605 - 0.625		Absorption edge of chlorophyll- slight sensitivity to chlorophyll
5	0.63 - 0.69	3	Sensitivity to chlorophyll, chlorophyll absorption for plant species differentiation
6	0.695 - 0.75		Indirect and minimal sensitivity to vegetation or noise
7	0.76 - 0.90	4	Sensitivity to vegetation density or biomass
8	0.91 - 1.05	5	Sensitivity to vegetation density or biomass
9	1.55 - 1.75	5	Sensitivity to water in plant leaves. Vegetation moisture management
10	2.08 - 2.35	7	Sensitivity to water in plant leaves
11	8.50 - 13.00	6	Thermal properties, sensitivity to waterstress and plant heat stress

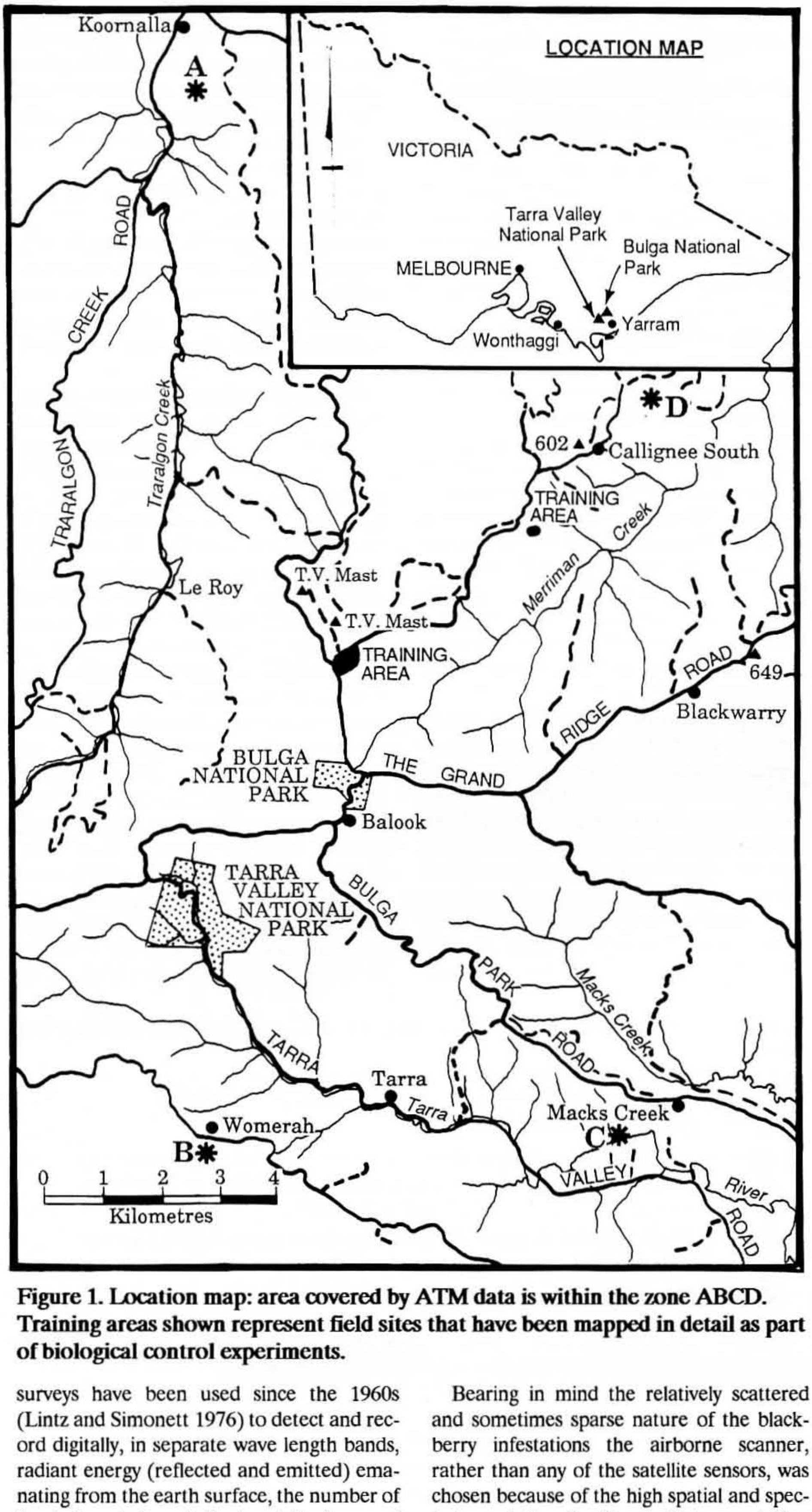


Figure 1. Location map: area covered by ATM data is within the zone ABCD. Training areas shown represent field sites that have been mapped in detail as part of biological control experiments.

surveys have been used since the 1960s (Lintz and Simonett 1976) to detect and record digitally, in separate wave length bands, radiant energy (reflected and emitted) emanating from the earth surface, the number of bands (spectral resolution) and the degree of ground detail (spatial resolution) being a function of the sensor array used and, especially in the case of ATM, the flying height. The digital data stream is stored in discrete picture element units (pixels) scan line by scan line, and is readily amenable to computer assisted image processing.

Bearing in mind the relatively scattered and sometimes sparse nature of the blackberry infestations the airborne scanner, rather than any of the satellite sensors, was chosen because of the high spatial and spectral resolution it offered. Data acquisition was made by Mr. J. Baxter (leader of the KTRI image processing and Geographical Information System group) between 2 pm and 3.45 pm, 28/2/88. At that time the scanner was owned by the National Safety Council of Australia (Victorian Division) and attached to a Beech Air King (fixed wing) aircraft flown at 2000 m above ground level (to give a nominal ground resolution of 5 m x 5 m) with some areas being also covered from 975 m (for a nominal ground resolution of 2.5 m x 2.5 m). The ATM data obtained yielded imagery of high visual quality (Figure 3).

Image analysis

The data manipulations encompassed by the term "image analysis" range from the simplest form of enhancement, wherein features of interest are emphasised by using a "linear (also known as contrast) stretch", to more complicated algorithms for registering distorted images to a standard map base and for removing shadow and atmospheric effects. Harris (1987), Campbell (1987), Curran (1985), and Richards (1986) offer descriptions of the use of various image processing algorithms. The challenge however is to select the functions and order of operation most applicable to the particular thematic mapping task at hand, having already identified the level of accuracy required and matched this with the appropriate budget support (e.g. see Lacey 1985, Hill 1989 in press).

The data for this project was processed with the microBRIAN (CSIRO and MPA 1988) PC-based image processing system (version 2.1).

Preprocessing

During February, blackberry patches have vigorous crowns of green foliage (Table 2, high DN value in Band 7). Accordingly visual interpretation of the raw data displayed in false colour (red-green-blue, RGB) allows recognition of blackberry patches, with the best delineation (contrast) in these terms being with the near infra-red (Band 7) assigned to either green or red colour guns and with visible green (Band 3) and visible red (Band 5) assigned to the other colour guns. A spectral response plot (Figure 2) confirms that the blackberry has maximum reflectance (DN155-254) value in Band 7.

From Table 1 it can be seen that the most suitable combination of wave bands is 3, 5, 7 and 10. Preliminary processing, using this data yielded confused distribution patterns of mixed and spatially inconsistent reliability. This was due to spectral overlap of blackberry with other vegetation. There was further confusion when known areas of blackberry were part of a mixed land cover (usually *R. fruticosus* with *Pteridium esculentum*, *Senecio linearfolius* and *Poaceae* spp).

It was therefore necessary to test, in spectral terms, for the various sources of confusion, and to apply corrections.

Routine procedures are used to eliminate "limb brightening" and geometric errors. The former was partly accommodated by eliminating 102 pixels from the edge of each

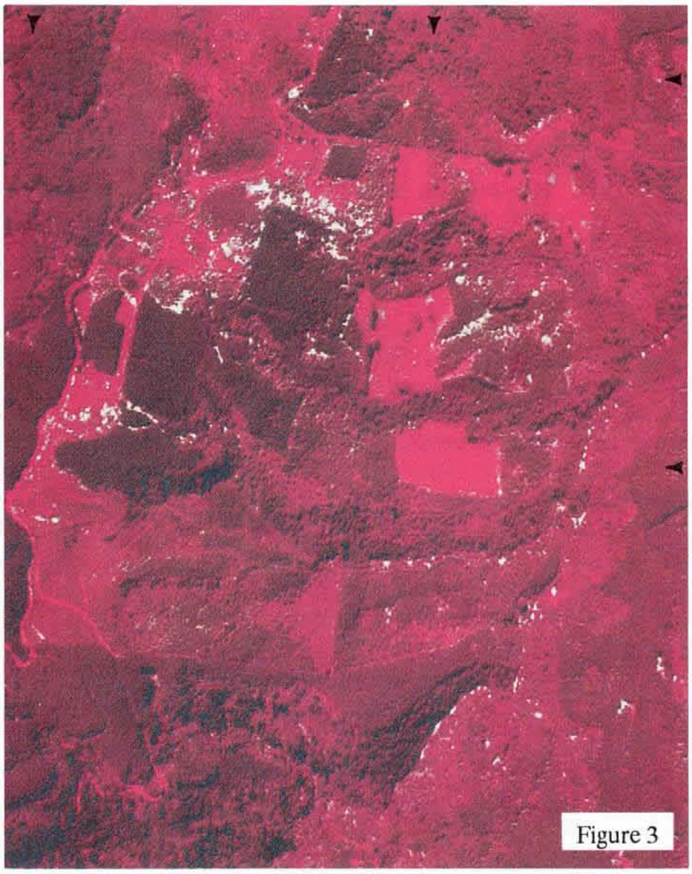
Table 2 - Reflectance (DN value, 8 bit data, scaled 0-254)

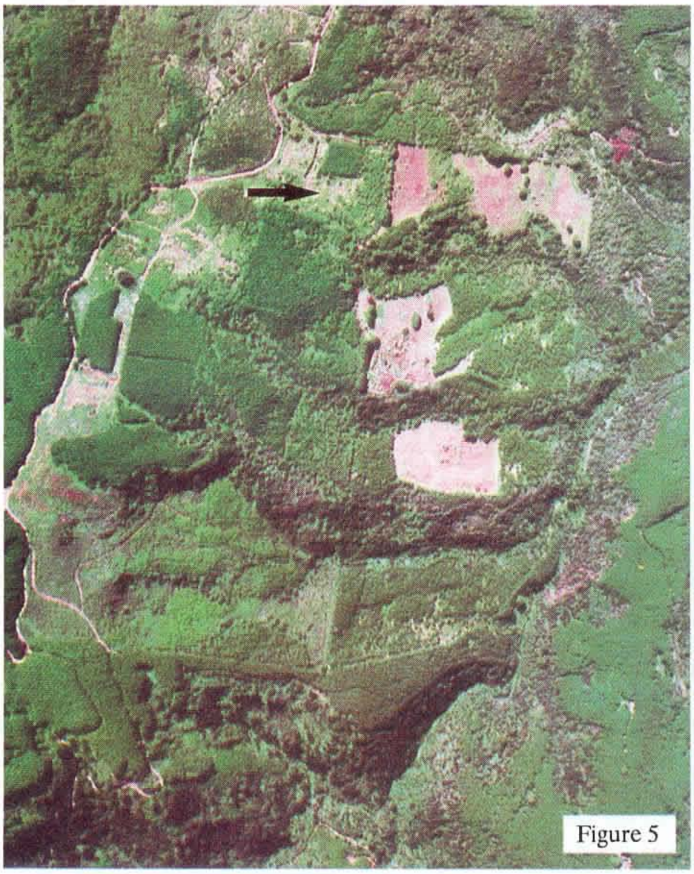
Band Features group	Band 1 (0.42-0.45 μm)			Band 3 (0.52-0.60 μm)			Band 5 (0.63-0.69 μm)			Band 7 (0.76-0.90 μm)			Band 9 (1.55-1.75 μm)			Band 10 (2.08-2.35 μm)			Band 11 (8.50-13.00 μm)		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Blackberry (*R. fruticosus*)	78.0	84.1	82.0	44.0	55.1	50.1	60.0	80.6	70.0	188.5	254.0	231.5	65.8	88.0	78.5	34.0	48.8	40.6	98.0	112.0	105.5
Blackberry with mixed vegetation	74.9	84.0	79.8	49.7	58.0	53.2	71.3	83.1	79.2	155.0	188.2	178.6	57.7	71.3	66.4	29.5	37.0	32.2	99.0	106.9	105.9
Pine (*P. radiata*)	55.2	79.9	62.4	19.1	33.2	25.6	22.1	44.8	32.7	78.8	166.7	120.7	17.0	31.8	24.7	10.0	22.0	15.3	77.1	92.0	85.2
Bracken (*P. esculentum*)	89.1	111.0	99.6	77.9	93.8	85.7	95.0	119.0	108.5	110.4	141.6	128.3	115.1	135.2	134.3	81.9	97.8	90.8	152.3	175.0	162.0
Clear ground with stubble	84.5	98.0	92.8	68.8	80.5	74.5	94.7	116.7	102.6	130.0	150.0	140.2	128.2	140.1	137.7	77.2	88.1	83.5	178.0	199.0	188.5

Note: Reflectance values were taken from training areas only. Values varied depending on the topography.

Table 3 - Steps in classification followed

	Major steps	Procedure	Results	Action
1.	Identifying image channels containing dominating information.	Image histogram channel cross-plot, correlation matrix, Density slicing.	Selected channels 3, 5, 7, 10.	Band 7 was selected for density slicing.
2.	Density slicing of channel 7.	Selection of band DN value representing features of interest obtained for minimal overlap with other features in the image.	Upper and lower DN value for *R. fruticosus* obtained	Rewrite band 7 assigning density sliced lower value to 0 and upper value to 254 (for 8-bit data). DN value should include the mixed vegetation with *R. fruticosus*.
3.	Features enhancement.	Log transformation of channel 3, 5 and 10.	Enhanced the dark features, in this case all tall trees and shrubs.	Rewritten log-transformed image value after linear contrast enhancement from total image histogram.
4.	Combining channels	Image channel combination	Obtained three rewritten channels after density slicing and log transformation (3, 7, 5 or 3, 7, 10) (step 2 and 3)	Channel 5 can be substituted with channel 10
5.	Display and print image	Assign display RGB colour groups (from step 5) channel 3 - blue channel 7 - green channel 5 - red	*R. fruticosus* patches appears as pale green patches of various shades (white to pale green) depending upon density of blackberry in the cover class	Overlapping classes from land cover with differing community structure (height) are easily distinguishable because of variations in hue, saturation and intensity over the three channels used to depict them
6.	Error matrix	Field checking and measurement for determining omission and commission errors	Selected variety of vegetation association including putative *R. fruticosus* patches checked and found to have been depicted accurately. Errors of commission and omission insignificant at 1:10000 because dither matrix in printer allows variable intensity to be represented as discretely coloured dots	Mapping procedures validated





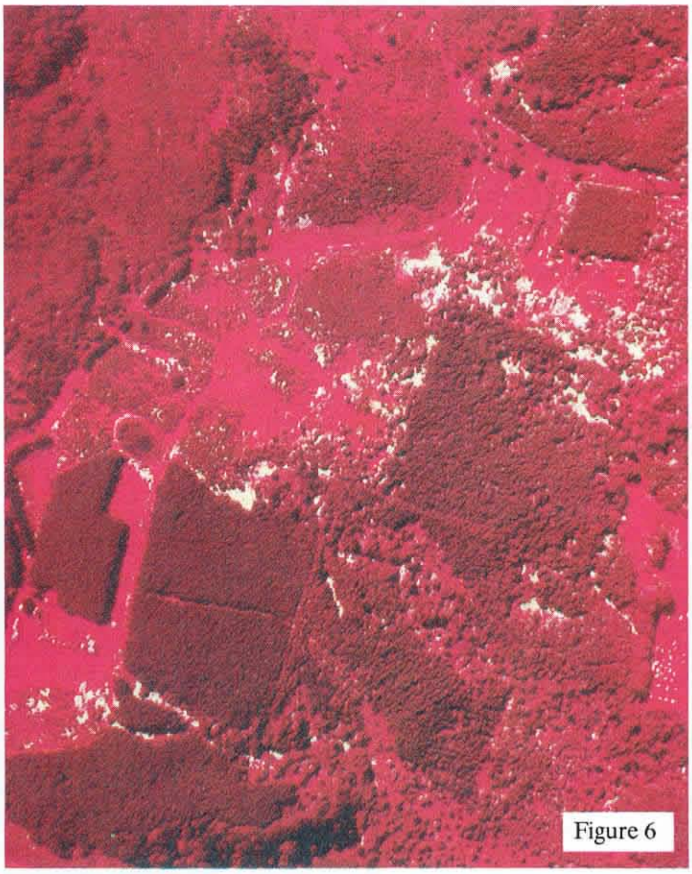


Figure 2 Near vertical aerial photograph of biological control field site (February 9th, 1988). Detailed knowledge of this area constituted part of the most detailed ground truthing of this project.

Figure 3 Image (linearly stretched) from raw data collected with ATM February 28th, 1988 from approximately 2000 metres AGL. Ground resolution of 5 m x 5 m.

Figure 6 Part of the area depicted in Figure 5 but at higher ground resolution (2.5 m x 2.5 m pixels). Scale 1.28 km wide x 1.1km high.

Note: North is to the top in each Figure.

Figure 5 Same area as depicted in Figures 2 and 3 showing the ATM processed image (Table 3 depicting blackberry distribution patterns (pale green/white) using data with 5 m x 5 m pixels. The training areas used for intense study were located within the area indicated by arrows (164 ha). The test areas used to verify the method evolved in the training area comprised the rest of the region shown here, plus a large contiguous area to the south (total of 1280 hectares). blackberry cover comprises 8.3% of the training area and 5% of the test area.

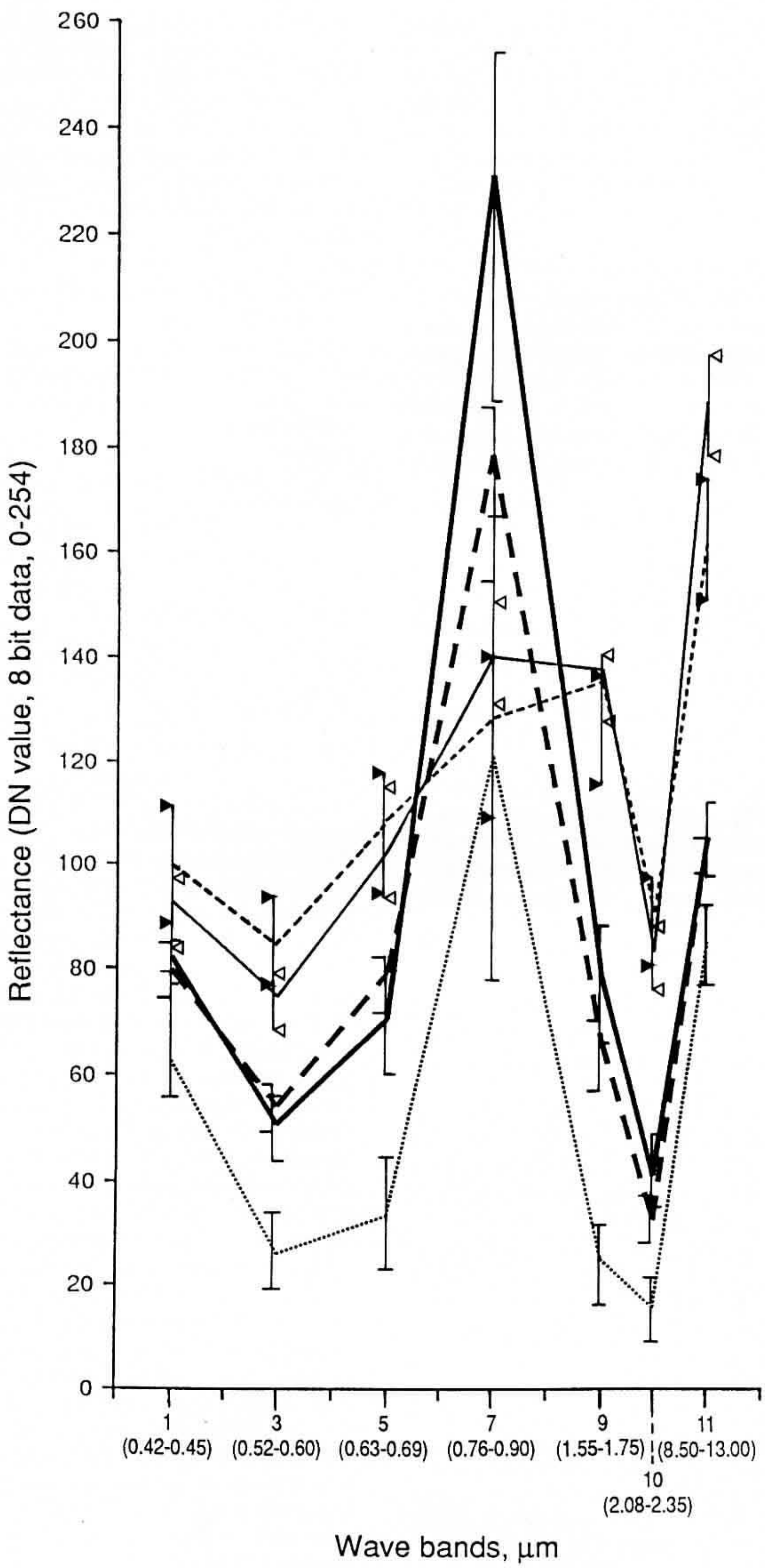


Figure 4 Spectral signatures as obtained from the image DN* value from training areas plotted against wave bands. Blackberry (*R. fruticosis*) [——], blackberry with mixed vegetation [— —], pine (*P. radiata*) [..........], bracken (*P. esculentum*) [-----], clear ground with stubble [——].

*DN Digital Number is the value of a variable recorded for each pixel in an image, usually in the range of 0-225 (Harrison *et al.* 1989)

run (Leckie 1987). Routines were tested for noise correction and colour enhancement (decorrelation stretch) for highly correlated bands (Gillespie, Khale and Walker 1986, 1987).

After this preprocessing the image processing options are, in broad terms: a) Image classification and/or b) Mapping by image transformation and enhancement

The results from either, need to be tested with field verification. Much of this for the present project was based on detailed mapping and field work in conjunction with biological field control experiments (e.g. Field *et al.* 1989).

Classification

Standard digital classification (e.g. the use of training areas) methods yielded distribution patterns for blackberry that included many errors of omission and of commission. These can be attributed to:

a) high correlation between wave bands (except Band 7)
b) overlap of spectral characteristics (Figure 4)
c) "within - class" variations (Williams 1989)
d) high data variation due to topographic effects

With ATM data from anywhere but low relief it is probable that a significant component of data variability is due to topographic effects. One technique used to remove this effect is band ratioing (Crippen, Blom and Heyada 1988). When applied to the current project, no significant improvement was achieved. Several vegetation indices (Tian 1987) were also tested to isolate information for blackberry. Confusion remained due to spectral overlap of blackberry patches and stands of *Pomaderris* spp saplings.

Mapping by image transformation and enhancement

Because it was the distribution of only a single species that was sought, and because the visual quality of the imagery was high, there was the possibility that transformation and enhancement of the data would yield unconfused blackberry distribution patterns. Accordingly, data transformation and display techniques, designed to mask out all non-blackberry cover classes were used as indicated in Table 3. The results are typified in Figure 5 which depicts one of the areas for which ground verification confirmed that confusion had been significantly reduced by adopting the transformation and enhancement approach.

The same method was applied to the data set with 2.5 m x 2.5 m pixels. The image processing method used for the final mapping was based on intense study of a well documented (biological control field site) area (Figure 2). Boundary mapping of blackberry patches improved in accuracy commensurate with scale of ground resolution (Figure 6).

Ground Verification

The image processing method used for the final mapping was based on intense study of a biological control agent release site (Figure 2). Data transformation and enhancement was undertaken (Table 3), until visual interpretation using the resultant imagery in the field, verified that mapping accuracy had been maximised. The results were improved between the (six) field verification sessions until all areas designated by image analysis as blackberry infestations proved to exist on the ground. Errors of omission were confined to blackberry patches smaller than 5 m x 5 m (or in the cases of the 2.5 m resolution data set, less than 2.5 m x 2.5 m), areas in shadow (e.g. small areas within the forest and in the shade of its edge), or areas along road sides that had been dust covered when the imagery was collected. The successful image analysis procedure was then applied to the rest of the data. Results are held at the KTRI and can be displayed on the microBRIAN system so as to enable percentage cover of blackberry to be obtained for any particular area depicted in the survey (e.g. see Figure 5).

Further Implications

At 2.5 m or 5 m resolution, remote sensing could prove to be an effective means of monitoring infestations of blackberry. Such monitoring would be desirable if more virulent strains of *P. violaceum* are approved for release.

At least two species of blackberry were present in the surveyed area, *R. polyanthemus* and a highly rust-susceptible variety of *R. ulmifolius*. The latter was noticeably more necrotic than the other at the time the ATM data was collected but we have not seriously attempted to differentiate between species of blackberry as yet, although detailed field mapping in areas adjacent to the experimental sites include large homogeneous patches of each of the blackberry types mentioned and could be key sites for any future attempt.

Airborne ATM has proven to be a means of mapping blackberry infestations and it is probable that the technique established in this study could be used to map other weed infestations such as bracken (*Pteridium esculentum*), The Department of Conservation Forests and Lands has recently purchased a Daedalus 1260 Thematic Mapper Simulator, so data such as that used in the present study can be collected for similar projects in the future.

Survey techniques using remote sensing have led to the adoption of new methods of archiving and storing data and results, such that they can later be integrated with other data sets in Geographical Information Systems (e.g. Hill in press).

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Erratum:

Plant Protection Quarterly Vol 4(4) page 152.

Please note that Figures 3 and 5 have been accidently transposed. i.e. The caption marked Figure 5 refers to Figure 3.