PROBLEMS OF APPLYING MULTISPECTRAL CLASSIFICATION TO UPLAND VEGETATION

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ABSTRACT

Digital number on Airborne Thematic Mapper imagery is shown to be related to floristic composition for a short transect between two semi-natural grassland communities in central Wales. The communities present a continuum in species-space which is thus expressed as a near continuum in spectral-space. Despite this a zonal rather than a gradient approach is often adopted where timely production of vegetation maps for the ecological evaluation of sites is required, particularly in upland areas experiencing rapid rates of habitat loss. Some of the procedural issues involved in the production of vegetation maps from high spatial resolution multispectral imagery are identified. The accuracy of multispectral classification depends on decisions made at the class definition and training data selection stage. The choice of ecological criteria used to define vegetation classes, the level of class subdivision employed and the decision to use either spectral or a priori vegetation classes are each significant. Supervised classification required class editing involving compromises between ecological and statistical validity. Topographically-induced illumination effects required the splitting of candidate classes, whilst pairwise divergence resulted in the merging of others. The 'unsupervised' approach was a useful preliminary to supervised classification and produced promising results in its own right with much less effort. The work was carried out in conjunction with another paper presented at this conference which deals with the manual photo-interpretation approach to the imagery (Hume et al 1986).

INTRODUCTION

The rate at which semi-natural grassland and moorland habitats in upland Britain are being lost or modified by afforestation, improvement of rough pasture and bracken incursion (Parry et al 1981) has created a need for timely vegetation mapping. For instance, the Nature Conservancy Council (NCC) requires vegetation maps as a basis for the designation of new protected areas, as a tool in their management, and for detecting change in habitat status in response to management and external pressures. Furthermore, county planning authorities now have a statutory duty to produce up to date maps of moor and heath within National Parks (HMSO 1981).

Panchromatic aerial photography has been the traditional data source for vegetation mapping by virtue of its availability, economy, spatial resolution and stereoscopic capability, but it is limited by its spectral range. Whilst near infrared wavelengths permit increased discrimination of communities (Hume et al 1986), the limited availability of archived near infrared photography hinders its use as an operational mapping tool. Satellite multispectral imagery has generally been at too
coarse a spatial resolution for habitat mapping and has suffered from problems of cloud cover in upland areas. The advent of pointable imaging systems such as that employed on SPOT offers the possibility of obtaining high resolution multispectral data at critical times in the phenological cycle. Its digital format permits multispectral classification, a seemingly rapid quantitative approach to the definition of vegetation boundaries. It is not the intention of this paper to examine the economics of SPOT imagery relative to alternative data sources but rather to illustrate some of the procedural issues and problems to be faced when using automated classification of high resolution imagery to produce maps of predominantly semi-natural vegetation in areas of rugged terrain.

DATA SET

The data was acquired by a Daedalus Airborne Thematic Mapper (ATM) at 12.17pm GMT on the 21st August 1984 as part of the Natural Environment Research Council's (NERC) Airborne Thematic Mapper Campaign. ATM bands 3, 4, 5 and 7 were used to represent bands XS1, XS2 and XS3 respectively, of SPOT's High Resolution Visible (HRV) sensors. The geometric instantaneous field of view (IFOV) was calculated to be 10.06 metres. Oversampling, particularly in the along track direction, produced pixels of approximately 8.5 x 6.0 metres at nadir. The image therefore is at a finer resolution and has a different aspect ratio than the 20 metre square pixel of the HRV's. However, similar conclusions pertained when the spatial resolution was degraded to an IPOV of approximately 20 metres (McMorrow 1985).

The 512 x 512 subscene comprised a 4 x 3.25 km area of moorland 6 kms south of Machynlleth on the Dyfed-Powys county boundary in central Wales (Plate 1). It included both semi-natural moorland core vegetation and examples of three rapidly encroaching cover types: conifer plantations, improved grasslands and areas of bracken incursion. Blanket mire on the valley floors gives way to acid grassland on valley sides and dwarf shrub heath on steep unvegetated scree slopes (Fig 3, NCC 1981).

THE PROBLEM OF VEGETATION GRADIENTS

Multispectral classification adopts a zonal approach in which discrete, repeatable classes are defined and boundaries are drawn between them. It has therefore been most successfully applied to agricultural lowlands where sharp boundaries can be recognized both on the ground and in spectral space between a limited number of mutually exclusive classes. In contrast, the moorland core vegetation can be shown to exhibit gradual boundaries which present a problem for any classification approach.

Floristic composition was examined over a short transect of 19 contiguous pixels between Nardus stricta (Mat-grass) and Molinia caerulea (Purple Moor grass)- dominated grassland (A - B, Plate 1) (Hume 1985). Its location on a scan line close to nadir and on almost flat ground was chosen to minimize viewing and illumination geometry effects. The ends of the transect were located on the ground by triangulation and the line was divided into 19 sampling units. The cover species was recorded at 90 regularly spaced points within a 6 x 3 metre sampling area centred on the sampling units - a total of 1710 readings. Digital numbers for the equivalent 19 pixels were extracted from the image and ratio'ed (Fig. 1a). It is recognised that there will be errors in positioning of the order of three pixels but the significance of the error is reduced by the similarity of the vegetation either side of the transect.
A floristic gradient can be seen between the two dominant species (Fig. 1b). Percentage nardus and percentage molinia are significantly correlated with the X33/XS2 ratio ($r_s = -0.80$ and 0.76 respectively).

Although results can not be extrapolated over the rest of the image, two conclusions can be drawn. Firstly, spectral classes do relate to meaningful vegetation classes defined on the criteria of percentage of dominant species, at least within the simplified conditions of the transect, so that a multispectral approach is valid. In view of this good agreement between floristic composition and spectral response alternative approaches using mathematical modelling might be explored. Secondly, since the vegetation represents a continuum in species-space (Fig. 2a) which is matched fairly closely in spectral space (Fig. 2b), decision boundaries between clusters will overlap and misclassification can be expected. Gradual boundaries invite subdivision into a larger number of small discrete classes. The finer the spatial resolution of the image the more such variation between a priori classes becomes theoretically detectable.

Despite its limitations the zonal approach is usually adopted where a rapid statement of the baseline status of vegetation is required in familiar map form.

APPLYING THE ZONAL APPROACH

If it is accepted that boundaries are to be defined, then this may be done visually from a false colour composite or by semi-automated means. The former approach allowed tone, texture and context to be used to rapidly produce a vegetation map which compared well with a 1:10,000 field vegetation map (Lume et al 1996). The latter approach proved more problematical, raising issues of class definition and training data selection.

UNSUPERVISED CLASSIFICATION

Unsupervised clustering is appropriate for this image where it is difficult to select homogeneous training samples of sufficient size, owing to topographic variations and the complexity of the vegetation itself (Townshend & Justice 1980). It is particularly applicable in situations where detectable within- and between-class variation is not adequately described by the available reference document (Fig. 3), and where spectral classes are expected to relate well to vegetation classes.

A migrating minimum-distance-to-means algorithm was used to cluster the whole subscene with increasing numbers of classes from 4 through to 16.

The term 'unsupervised' is a misnomer. The division of spectral space, and hence the resulting image, is predetermined by the number of classes chosen, as well as by any decisions regarding cluster thresholds. A method analogous to ordination and the polythetic divisive clustering techniques used in ecology (Hill et al 1975) would be preferable because this allows measurement space to be unbiasedly inspected for natural clusters at various levels of association. Twelve classes yielded an image comparable to the 1:25,000 vegetation map and to the supervised class map produced with much greater effort.

Whilst spectral classes related well to vegetation classes along the
transsect, a qualitative evaluation against the 1:25,000 vegetation map (Fig. 3) and a 1:10,000 field vegetation map showed that the spectral classes for the whole scene were difficult to translate into meaningful vegetation classes. They related as much to topographically-induced differences in illumination as to real vegetation differences. The most marked spectral contrasts within the moorland core are seen by clustering with a small number of classes and proved to be aspect controlled. Atmospheric correction for haze followed by the use of ratioing can minimize the problem (Smedes et al. 1971).

Clustering proved a useful preliminary to supervised classification, showing that it would be necessary to classify north and south-facing components separately and subsequently recombine them in order to achieve unimodal classes. Within-class variation was also usefully highlighted. The resulting 'pepperpot' pattern represents either ecological information or unwanted 'scene noise', depending on the intended purpose of the classification. Unless revision of previously improved pastures is of interest as a habitat it is suggested that they and conifers are delimited visually and masked from the image before classification of the moorland core vegetation.

In conclusion, despite the need for an iterative approach, the unsupervised method yielded promising results with much less computing and operator time than supervised methods, but the final product is complicated by topographic effects. It is recommended as a preliminary to supervised classification for high resolution images of complex terrain and vegetation.

SUPERVISED CLASSIFICATION

A list of classes must be devised which are simultaneously exhaustive, of information value and spectrally separable, requirements which proved difficult to reconcile. Class definition was an iterative process influenced by the availability and character of the training data. Candidate classes chosen were those regarded as valuable by the NCC and mapped in Figure 3, but were modified to meet requirements of separability, statistical validity and practical considerations.

Sixteen candidate classes were identified, fourteen from the NCC map, one new class (16) was added from field observation and one added (9) as a result of preliminary inspection of the histogram for the nardus class. Training data was selected and class editing followed, resulting in eleven classes (Table 1). The editing process involved the splitting of bimodal class 5, guided by unsupervised clustering and after inspection of histograms, in order to avoid serious violation of the Gaussian assumption for a parametric classifier. Aspect-controlled differences in irradiance, species composition and wind turbulence seem to explain the need to split the nardus class, whilst management practices also play a part for the improved grassland class.

A spectral coincidence plot (Fig. 4) and transformed pairwise divergence (Swain & Davis 1978 p172) were used to identify overlapping classes. Results showed that calluna mire classes (11 - 13) should be merged, which although ecologically viable, is unfortunate in view of the importance of assessing their conservation value. Two other classes (6 & 7) were merged on the same grounds. A cluster analysis of the divergence values might have suggested amalgamating classes 4 to 7 but this would reduce its ecological validity. Finally, three classes (10, 14, 16) were omitted because insufficient pixels could be found to retain the equal training populations desirable when the classifier to be used employs equal prior probabilities.
Selection of the training data itself was problematical, both because of the terrain and the limitations of the reference document used. Despite its statistical desirability (Townshend 1981 p41), random sampling was feasible only for classes covering large areas. Purposive sampling had to be used for classes of small areal extent which tended to be mapped as mosaics at 1:25,000. Field checking showed greater within-class variation for some classes than others. Prior probabilities could not be varied for the hybrid maximum likelihood classifier used, so that training population had to be approximately equal for each class (Swain & Davis 1978 p157). It would be more desirable to allow classes with larger variances to be represented by a larger sample. The size of the training set is thus a compromise between the limitations of the classifier, the requirements of measurement complexity (10n to 100n pixels per class, where n is the number of bands (Swain & Davis 1978 p151)), the variability to be represented and the number of pixels actually available.

The training sample for each class is distributed between a sites, the number of which may be dictated by software restrictions or the amount of collateral data available, but is ideally influenced by characteristics of the vegetation such as stand size (Townshend 1981 p43). A size of 5 x 5 pixels was chosen as a compromise between locational accuracy and the variability to be represented.

The hybrid classifier used a parallelopiped algorithm for unambiguous pixels within a two sigma threshold, a minimum-distance-to-means rule for those outside and the maximum likelihood rule for the remainder. Thus there was no reject class. An average accuracy of 80% was obtained for the training set, but this is liable to be a biased and inflated estimate since an independent test set was not used (Mead & Szajgin 1982). The pattern of errors (Table 2) was well predicted by the pairwise divergence measure so that it is a potentially useful technique for identifying problem classes and assessing the likely results of their removal prior to full classification, in a similar way to its use by Hoffer et al (1975) for reducing unsupervised clusters to manageable numbers.

The large errors of commission for class 5 are explained by its high standard deviation (Fig. 5). 'Cleaning' of training data to exclude reverted and untreated patches would reduce the size of the cluster and therefore improve classification accuracy (Maxwell 1976), but one must decide the degree of acceptable internal variation. Whilst differential irradiance on slopes of different aspects and steepness but otherwise similar vegetation did hinder classification, in other cases topographic effects improved results. The separability of dwarf shrub heath from calluna mires and conifers has probably been improved by its restricted occurrence on north- and east-facing slopes. Furthermore, where sharp discontinuities in slope were expressed as a sharp vegetation gradient quite 'clean' boundaries could be achieved on the classified image. Rough and improved grassland classes would probably be better separated in May when molinia and bracken still retain much brown leaf tissue.

CONCLUSION

The validity of the final classification depends as much on four decisions taken at the class definition and training data selection stage as on the inherent spectral properties of the vegetation:

1. The choice of ecological criteria; each criterion can potentially produce
a slightly different statement of vegetation status against which to evaluate the result, so that the accuracy of the classification will depend on the appropriateness of the ecological variables chosen. This field data alone is to be used (Fig. 3) in are based on have been shown to relate

2. The degree of sub-division of classes; a compromise must be reached between the large number of unimodal classes suggested by the complex terrain, and the number which it is practical to handle. The desired level of subdivision may initially be dictated by user requirements but, critically, must also suit the spatial and radiometric resolution of the image. Hence hierarchical classification schemes have been devised (Howard & Schade 1982). Candidate classes must be split or merged to meet the requirements of statistical validity and spectral separability, and the final set of classes is a compromise between statistical and ecological validity. Pairwise divergence is a useful way of predicting the improvement in accuracy achievable by various class editing options.

Within-class variation becomes apparent at high resolutions (Markham & Townshend 1981). The image (Plate 1) is detecting vegetation patterns finer than those mapped at 1:25,000 (Fig. 3). Small scale variations in stand composition and shadow are not averaged out so that each cluster occupies a larger area in spectral space, particularly for Coriaceae grassland, conifers and improved pasture where contrast between adjacent scene components is high. Where interest is solely in semi-natural vegetation, it is suggested that other classes are first screened out manually or by classification at coarser resolutions. If improved grassland and conifers are to be included then further subdivision is required according to species, age and management in order to avoid the large standard deviations which have adversely affected the accuracy of the other classes. If existing vegetation maps are to be used to define training areas or to verify spectral classes resulting from unsupervised clustering, then the map must be at a scale suitable to the resolution of the image with a similar level of generalisation for each class. Otherwise, as here, the accuracy of the supervised classification is constrained by that of the reference document. A 1:10,000 vegetation map is more suitable for an IFOV of 10 metres.

3. The approach to be adopted in linking vegetation classes and spectral properties; only the two most widely available strategies have been examined here, unsupervised and supervised classification. Hybrid methods are recommended for complex terrain and cover types (Hoffer et al 1976, Fleming et al 1975, Townshend 1981) but software limitations prevented their use - a situation also currently likely to apply in many government organisations actively involved in habitat mapping in Britain.

4. The selection of representative training data for supervised classification; The number of training areas, their population and method of selection is critical. There is a compromise between the requirements of statistical rigour and the practical problems of locating oneself on the ground, the number of pixels actually available in a given class, deciding what constitutes an acceptable degree of within-class variability and the limitations imposed by software.
Acknowledgements: the authors wish to thank Mr M. Barnsley and Mr T. Elsey (University College London), Mr J. Brunner and Dr A. Morton (Imperial College London) and Mr R. Mcmorrow and W. Hume for their help and encouragement. The image was kindly made available by NERC.

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Fig 3: NCC Vegetation Map

B DWARF SHRUB HEATHS:
B1 Sub-montane Calluna vulgaris heaths:
B1a Calluna dry heath
B1b Calluna-Sphagnum damp heath
B3 Vaccinium myrtillus-Empetrum heaths:
B3a Southern Vaccinium heaths

C GRASSLANDS:
C1 Agrostis-Pestuncus grasslands
C2 Nardus stricta grasslands:
C2a Sub-montane Nardus (spp.poor)
C3 Juncus squarrosum grasslands:
C3a Spp. poor Juncus squarrosum
C4 Molinia caerulea grasslands:
C4a Spp. poor Molinia grassland

G BLANKET BOGS (Ombrogenous mires)
G2 Trichophorum-Calluna mire:
G2a Sphagnum-rich T/C mire
G2b Rhaconitrium-rich T-C mire
G3 Molinia caerulea-Calluna vulgaris mire
G4 Calluna-Eriophorum vaginatum mire:
G4e Vaccinium-rich C-E mire
G4f Eriophorum-dominated mire

H FLUSH BOGS & FENS (soligenous & topographic mires)
H2 Juncus-moss mire
H2a Juncus effusus-Sphagnum recurvum mire

M MOLINIA-COMPLEX P PTERIDIUM
V VACCINIUM MYRTILLUS U ULEX
Vvi VACCINIUM VITIS-IDAEA
I IMPROVED/ENCLOSED O OUTCROPS OF AGRICULTURAL LAND
COMFERS / LIMIT OF MAPPED AREA

Mapped in 1980 at 1:25,000, redrawn from NCC report (1981)
### TABLE 1a: SIXTEEN ORIGINAL CANDIDATE CLASSES

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<th>Molinia - Erophorus - Triophorum - Sphagnum blanket mire (M)</th>
<th>Nardus grassland (C2a) on north-facing slopes</th>
<th>Nardus grassland (C2a) on south-facing slopes</th>
<th>Juncus effusus - Sphagnum recurvum flushes (H2a)</th>
<th>Molinia - Calluna embrogenous mire (G3)</th>
<th>Triophorum - Calluna embrogenous mire (G2a)</th>
<th>Calluna - Erophorus embrogenous mire (G4)</th>
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<th>Dwarf shrub heath, (Calluna dry heath / Calluna - Sphagnum damp heath (B1a/B1b))</th>
<th>New forestry on M Complex</th>
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### TABLE 1b: FINAL ELEVEN CLASSES

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### TABLE 2: CONTINGENCY MATRIX FOR TRAINING SET

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ERRORS OF COMMISSION | 19   | 0    | 34   | 117  | 63   | 44   | 46   | 22   | 24   | 74   | 446  | 2236            | 80.1             |