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A method for vegetation stratification using scale-related, vegetation-enhanced satellite imagery

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ABSTRACT

A method for visual vegetation stratification and pattern refinement, using scale-related, vegetation-enhanced satellite imagery, is described. The method simplifies colour assignment, facilitates accurate vegetation mapping and could lead to balanced floristic classifications.

UITTREKSEL

'n Metode vir visuele plantegroei-stratifikasie en patroon verbetering wat van skaalverwante, plantegroei-versterkte satellietbeelde gebruik maak, word beskryf. Die metode vereenvoudig kleurtoekenning en vergemaklik akkurate plantegroei-kartering en kan tot meer gebalanseerde floristiese klassifikasies lei.

INTRODUCTION

In vegetation sampling (Werger 1974) the subjective selection of sample sites, based on vegetation homogeneity, can only be done effectively by an operator with considerable experience. In addition, there is often a lack of repeatability in the methods and a tendency to ignore vegetation dynamics by only sampling those areas representative of 'good' vegetation.

Stratified random sampling overcomes these problems and increases sampling efficiency by ensuring adequate representation of subdivisions (Elliott 1983). Furthermore, in contrast to random or systematic sampling, the heterogeneity of vegetation, in terms of possible number of communities, can be related to the number of stratified units. Stratification also facilitates the avoidance of transitions which generally do not contribute more information than the adjacent communities (Werger 1974).

Stratification of vegetation prior to floristic sampling entails primarily the categorization of vegetation according to structural characteristics. The categories can be further refined according to the factors apparently responsible for differentiating the strata. The most important factor is usually taken to be topography but others such as geology, pedology, climate or combinations of the four may also be decisive.

Problems encountered with vegetation stratification when using aerial photographs include radial distortions, altitude-related scale differences and often inconvenient scales, which do not facilitate precise vegetation mapping. The excessive detail present in aerial photographs can be potentially confusing and time consuming for stratification, especially for small-scale work. The use of small-scale, almost orthographic satellite imagery for stratification overcomes these problems but introduces the problems of pattern interference by factors such as soil, and colour assignment where patterns are formed by unfamiliar colours and textures. This paper describes a method for vegetation stratification, using satellite imagery that can overcome the problems of pattern interference and colour assignment and facilitates later pattern refinement.

CONVENTIONAL USE OF LANDSAT DATA IN VEGETATION STRATIFICATION

False colour images

The Landsat multi-spectral scanner (MSS) records radiance from the earth's surface in four spectral bands: 500–600, 600–700, 700–800 and 800–1100 nm, usually referred to respectively as bands 4, 5, 6 and 7. These data are obtainable in image or digital form. The ground resolution of the system is nominally 79 × 56 m which corresponds to a picture element of about 0,30 × 0,22 mm at a scale of 1:250 000.

The MSS collects six lines of data simultaneously using a set of six detectors for each spectral interval. The mismatch in these sets is one of the major causes of noise in MSS data, which is apparent as striping with a periodic cycle of six lines at extreme radiometric enhancements.

Traditionally Landsat MSS data have been used in mapping at scales between 1:1 000 000 and 1:250 000 (under special circumstances up to 1:100 000 or even 1:50 000 scale) in the form of false colour images, i.e. bands 4, 5 and 7 displayed respectively as the colour primaries, blue, green and red.

This type of display suffers from two disadvantages: firstly only three of the four bands can be displayed, with a possible loss of crucial information in band 6. Secondly, because of the high degree of correlation between bands (Table 1), a very limited re-

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gion of the available three-dimensional colour space is utilized: live vegetation appears exclusively in various shades of red, depending on its structure and vigour.

TABLE 1. — Correlation matrix of the radiance values of the Landsat MSS data, in the four Landsat MSS bands, for the study area

Band	4	5	6	7
4	1,0			
5	0,88	1,00		
6	0,71	0,62	1,00	
7	0,59	0,47	0,94	1,00

Digital multispectral classification

Digital multispectral classification methods have been used successfully in crop mapping. The methods have proved to be a problem in the stratification of natural vegetation, particularly under southern African conditions. The reasons are mainly: rugged topography (crops are normally grown on level fields), heterogeneity of stands with the consequent problems of selecting 'typical' training sites of sufficient size (i.e. several hectares in size) for the extraction of spectral signatures and the interference of soil reflectance caused by incomplete canopy cover.

Furthermore, this method relies exclusively on spectral characteristics and cannot make use of the contextural or contextual information consciously or subconsciously available to the human interpreter.

DIGITAL ENHANCEMENT OF LANDSAT DATA

In the alternative approach of enhancement of the Landsat MSS data by digital image processing followed by visual interpretation, the versatility of the human analyst is assisted by means of quantitative enhancement of vegetation differences in stratification but particularly in pattern refinement.

Principal Component Analysis

Principal component analysis (PCA) provides a convenient method of data compression and removal of redundant correlation between bands (Lasserre *et al.* 1983). Experience has shown that typically more than 99% of the total variance in the data is retained in the first three principal components (Table 2), the maximum which can be accommodated in any colour display.

TABLE 2. — Variance in terms of proportional eigenvalues for the first four principal components of the Landsat MSS data for the study area

Principal Component	First	Second	Third	Fourth
	0,872	0,106	0,016	0,005

The first component represents shadow-enhanced topography and overall terrain brightness differences, whereas the second and third reflect the spectral differences in surface cover. Although the third component normally contains considerably less variance than the second, this may be crucial information for stratification. The fourth component contains predominantly noise.

For optimum results PCA must be based on the statistics of a (composite) subscene, approximately equally representative of the relevant floristic subdivisions, of the area to be stratified. The three principal components may be displayed in any combination of the colour primaries. However, particularly in regions of large variations in overall brightness, such as in areas of rough topography, this results in multicoloured imagery which is difficult to interpret.

A much more informative product can be obtained by displaying the first three components respectively as the Munsell colour parameters, brightness, hue and saturation.

Display in the Munsell colour space

In order to generate a practicable colour display, the components representing the Munsell colour parameters must be converted into the colour primaries, blue, green and red by computation, special care being taken that visual hue differences in the display truly reflect numerical differences in the data (Malan & Lamb 1985). The first and third components are first contrast-stretched to about 1–2% of the data in maximum and minimum values. The distribution of the first component is approximately Gaussian (Figure 1) while a histogram equalization stretch is applied to the second component (Figure 2). These stretch lookup tables must be based on the statistics of the representative subscene used for PCA.

In the final product the overall impression of terrain brightness of the original image is retained, thus facilitating registration with overlays and later pattern refinement. The effect of the histogram equalization stretch of the hue component is to spread the spectral differences of the cover over the complete hue gamut (as modified in saturation by the third component) as opposed to the limited range of hues in the conventional false colour representation (compare Figures 3 & 4).

Filtering

When vegetation mapping is to be done at a scale where the shortest cross distance of a mappable unit is greater than a ground resolution of 79 × 56 m, the original resolution of the Landsat MSS data could lead to a product with too much small detail. Prior smoothing of the data produces a scale-related product which facilitates stratification and pattern refinement.

The minimum colour-stratified area is given by 12,56 n mm^2 with a shortest cross distance of 4 mm (Rutherford & Westfall 1986). The value of n is determined by the minimum number of samples required for possible floristic subdivision of a colour-stratified area which is dependent on scale as related to sample area and spacing as well as the area of the colour-stratified unit. For example, with n=4, full resolution Landsat MSS data could therefore theo-

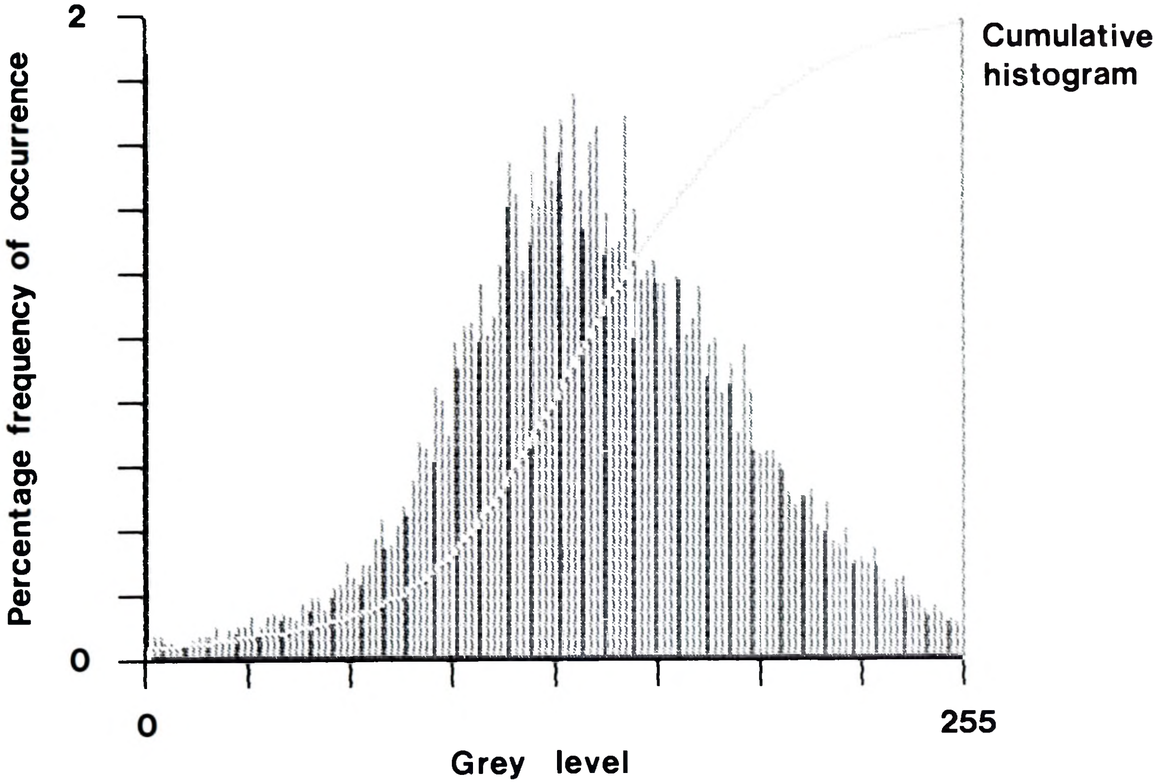

FIGURE 1. — Histogram showing the approximately Gaussian distribution of the first principal component, displayed as the Munsell brightness parameter.

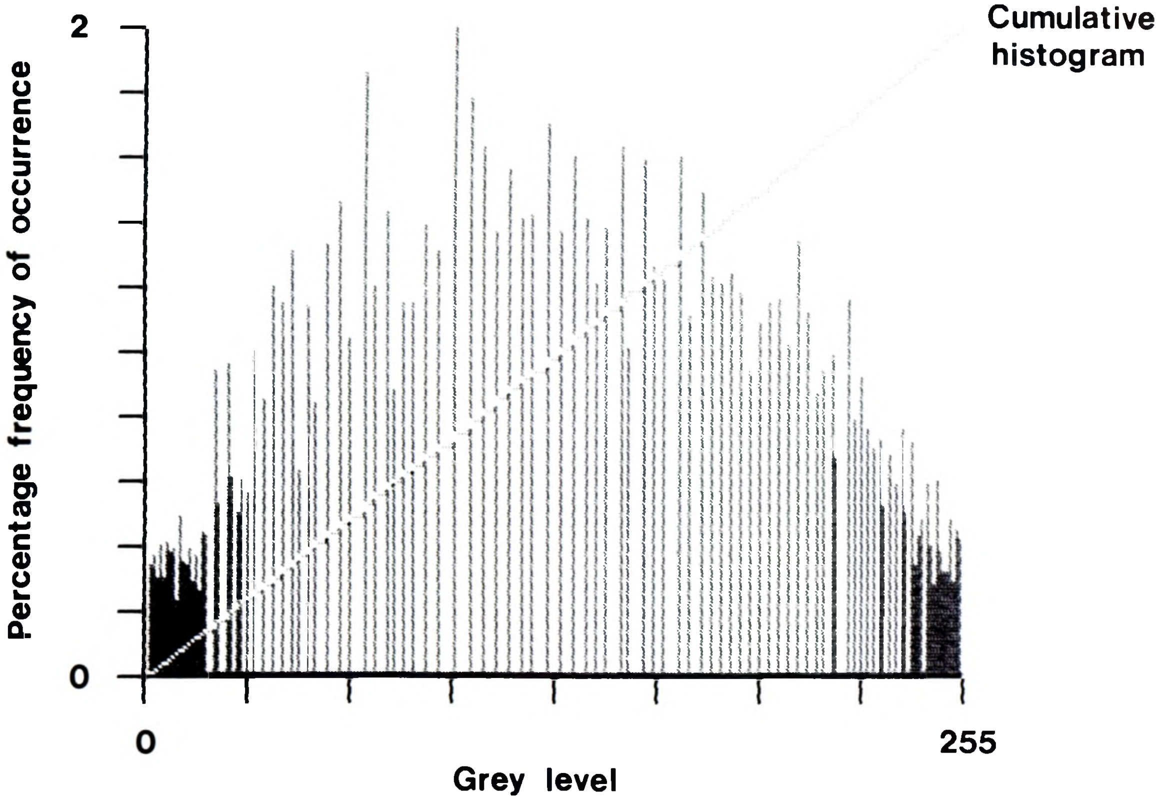

FIGURE 2. — Equalized histogram of the second principal component, displayed as the Munsell hue parameter.

retically be used for vegetation stratification up to a scale of 1:10 000. However, PCA dramatically enhances noise in the data in the higher principal components, particularly the striping in Landsat MSS data. The application of a median filter with a kernel at least six lines wide smoothes the data and removes striping effectively. Consequently, in practice, a median filter with a minimum kernel size of 6 × 9 picture elements corresponding to a square ground resolution of about 24 ha, is used. This corresponds to a maximum useful working scale of almost 1:50 000.

The (first) brightness component is excluded from the filtering process, to retain fine detail in the representation of topography, which assists in pattern refinement as well as in the identification of ground control points for registration with map overlays.

PATTERN REFINEMENT

Pattern refinement refers to the process of modifying the stratified units, usually after sampling and classification of the vegetation and prior to mapping floristic units. This process includes the grouping together of similar, smaller, discreet areas and subdivision of larger, uniform colour-stratified areas by contextual comparison if required, with suitable, simplified topographical, geological, pedological or meteorological overlays and sample-set classification at the given working scale. The choice of any or all of these overlays is determined by the range of variation exhibited by the overlays that can relate to the structural variation. For example, smaller units of differing colour can be grouped together on the basis of floristics and soils or topography while larger, uniform units could be subdivided on the basis of floristics and geology or climate in order to refine the patterns.

Minor inaccuracies can occur in the registration of Landsat hard copy images and other maps at the same scale used for overlays which are attributed to differential stretch and shrinkage caused by fluctuating humidity as well as some obvious inaccuracies in the maps. These errors can be compensated for by shifting local fit to achieve the maximum number of registration points rather than be compounded by maintaining fixed registration points. However, the effect of stretch and shrinkage can be further reduced by the use of dimensionally stable transparencies of both satellite images and other maps, where available.

RESULTS

The results of colour-stratification using scale-related vegetation-enhanced satellite imagery are given for a portion of the Transvaal Waterberg in the north-western Transvaal (Rutherford & Westfall 1984) at 1 250 000 scale. The area has a highly diverse topography with a consequently high variation in vegetation structure which is inferred from the variation in colour pattern. The vegetation is mainly representative of Sour and Sourish Mixed Bushveld veld types (Acocks 1975). Structural heterogeneities related to topographic diversity were indicative of potentially small stratification units and the value of n=4 was accordingly assigned. This corresponds to a map area of 50 mm² which is equivalent to 320 ha. The appropriate filter kernel size was therefore 32 × 22 picture elements. A contrast-stretched false-colour MSS image (acquisition date March 1981) is shown in Figure 3. A vegetation-enhanced image, at the original resolution of the same scene, is shown in Figure 4, which illustrates the complexities of colour assignment exacerbated by noise, particularly six line striping. A scale-related, vegetation-enhanced image at the hard copy scale of 1:250 000 of the same scene is shown in Figure 5 with resultant simplification of colour pattern to form stratified units.

INTERPRETATION

A critical prerequisite for successful stratification is the choice of the optimum data acquisition date for maximum differentiation between the structural subdivisions. Because the four wettest months in the study area are from November to February, the data acquisition date of March ensured high vegetation cover with minimal cloud interference.

The inputs required from the user are location of study area, working scale and data acquisition dates of scenes required. Primary colour-stratification is automated after these inputs and is, therefore, objective and time and labour saving. Many researchers use topographic, geologic, pedologic or meteorologic maps for comparison with floristic units or simply to show the variation in these factors. Unless working scale is standardized at the outset of a project, comparisons are difficult. Overlays at a standardized scale are used for pattern refinement and can also be used for later comparisons with floristic units in addition to the enhanced Landsat MSS image. They can, therefore, serve dual purposes and their effective use is increased.

Training sites would often be required for unsimplified images (Westfall & Malan in press), whereas the use of scale-simplified images largely overcomes the need for this training. Furthermore, scale-related stratified units should improve floristic classifications by providing a balanced distribution of sample sites commensurate with vegetation heterogeneity and the amount of detail required for a given working scale. It should be pointed out that, like PCA, the colour stratification by vegetation enhancement is highly scene-dependent. In practice, however, this is not a great disadvantage because one Landsat scene covers 34 000 km². Also multiples of this size can be treated identically if they are contiguous images on one north-south Landsat swath.

The use of satellite images, which have better geometric fidelity than aerial photographs, also simplifies the process of accurate vegetation mapping, especially where first-order stereo-restitution instruments are not available. This ensures greater mapping precision when compared to base maps and facilitates the effective use of overlays for comparison or pattern refinement.

The proposed methods also ensure objectivity because the primary colour-stratification process is computerized, which produces repeatable stratification units. It is doubtful that subjectively stratified units could be repeated by different workers. This

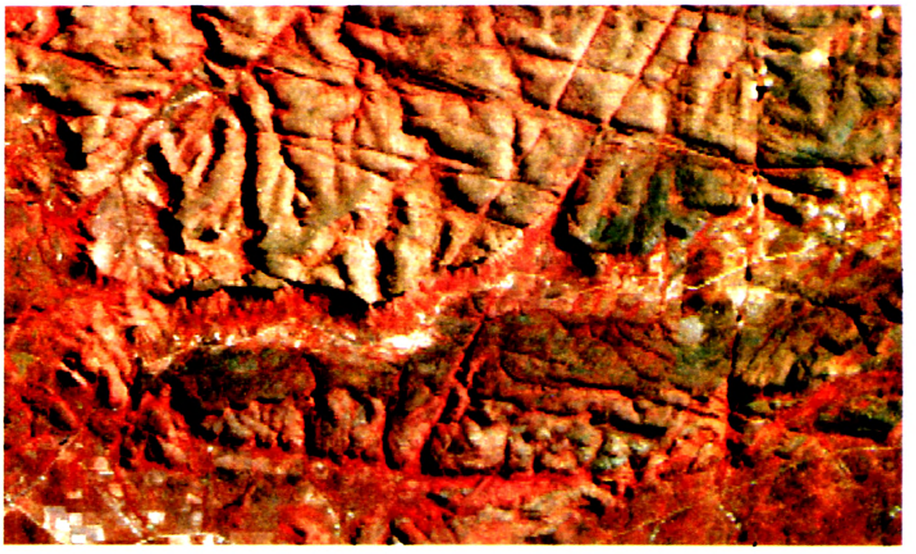

FIGURE 3. — A contrast-stretched, false-colour, multispectral-scanner (MSS) image of a portion of the Transvaal Waterberg with limited range of hues. Scale 1:250 000.

FIGURE 4. — A vegetation-enhanced image at the original resolution of the same scene as shown in Figure 1 using the complete hue gamut.

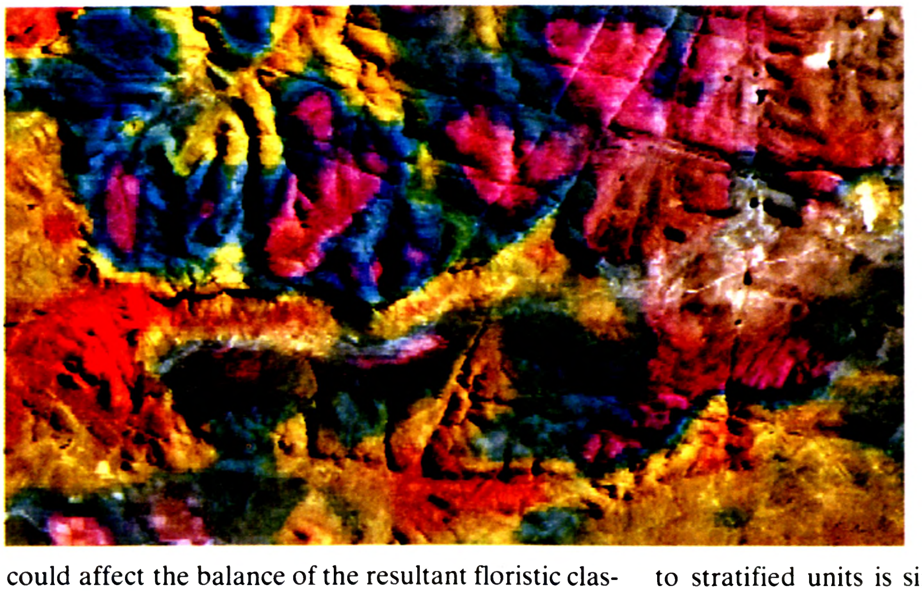

FIGURE 5. — A scale-related vegetation-enhanced image of the same scene as shown in Figure 2 showing simplification of colour pattern to form primary stratified units.

could affect the balance of the resultant floristic classifications and could be especially significant in comparisons over time.

CONCLUSIONS

The proposed methods of vegetation stratification prior to floristic sampling are objective, and time- and labour-saving. The process of colour assignment to stratified units is simplified. The stratified units are related to working scale and the structural heterogeneity present in the vegetation. Overlay comparison and accurate vegetation mapping are facilitated and more balanced floristic classifications can be expected. Landsat data are generally more detailed than required for vegetation stratification at scales smaller than 1:50 00 and hence filtering is necessary.

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REFERENCES

ACOCKS, J. P. H. 1975. Veld types of South Africa. *Memoirs of the Botanical Survey of South Africa* No. 40.

ELLIOTT, J. M. 1983. *Some methods for the statistical analysis of samples of benthic invertebrates.* Kendall, Wilson.

LASSERRE, M., MALAN, O. G. & TURNER, B. 1983. *The application of principal component analysis to Landsat MSS data.* Proceedings of seminar on Principal component analysis in the atmospheric and earth sciences, Pretoria 7–8 February 1983.

MALAN, O. G. & LAMB, A. D. 1985. *Display of digital image data; quantitative and optimal.* Proceedings of the third South African symposium on Digital image processing, Durban 22–23 July 1985.

RUTHERFORD, M. C. & WESTFALL, R. H. 1984. Sectors of the Transvaal Province of South Africa. *Bothalia* 15: 294–295.

RUTHERFORD, M. C. & WESTFALL, R. H. 1986. Biomes of southern Africa — an objective categorization. *Memoirs of the Botanical Survey of South Africa* No. 54.

WERGER, M. J. A. 1974. On concepts and techniques applied in the Zürich-Montpellier method of vegetation survey. *Bothalia* 11: 309–323.

WESTFALL, R. H. & MALAN, O. G. in press. *A comparison of vegetation units derived from vegetation-enhanced satellite imagery with the vegetation units derived from the floristic classification of the farm Groothoek, Thabazimbi District.* Proceedings of the symposium on Pattern recognition in remote sensing and geophysics.