Bothalia 14, 2: 271–282 (1983)

Remote sensing and vegetation mapping in South Africa

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ABSTRACT

Effective use of remote sensing techniques for vegetation mapping and monitoring is a function of scale, resolution, season of imagery, kind of vegetation, sensor and spectral sensitivity, processing of the remote sensing product and speed and precision of transfer of information into a map product.

The kinds of imagery, types of data and general relationships between scale of study, scale of mapping and scale of remote sensing products that are appropriate to the South African situation for visual and digital analysis are presented. The type of remote sensing product and processing, the type of field exercise appropriate to each, and the purpose of producing maps at each scale are discussed. Lack of repetitive imagery to date has not allowed for the full investigation of monitoring potential and careful planning at national level is needed to ensure availability of imagery for monitoring purposes. Map production processes which are rapid and accurate should be utilized. An integrated approach to vegetation mapping and surveying, which incorporates the best features of both visual and digital processing, is recommended for use.

1. INTRODUCTION

'Remote sensing is the acquisition of physical data of an object without touch or contact' (Lintz & Simonett, 1976). Effective use of remote sensing techniques for vegetation mapping and monitoring is a function of scale, resolution, season of imagery, kind of vegetation, sensor and spectral sensitivity, processing of the remote sensing product, and speed and precision of transfer of information into a map product. The field of remote sensing has expanded over the past thirty years from the use of small scale panchromatic photographs taken from aircraft primarily for trigonometrical work, to a wide variety of remotely sensed products used in many disciplines and which are taken from various platforms ranging from helicopters to spacecraft.

The current awareness by planners and land-managers of the important role that vegetation plays in maintaining a stable environment has created a demand for vegetation mapping and monitoring at various scales. The majority of these surveys can be more efficiently and accurately done with the aid of remotely sensed products. However, although air photographs have been widely used as support products in vegetation studies in this country, there have been few published studies on the comparative effectiveness of different products for specific purposes, such as that by Jarman (1977) in the eastern Orange Free State, who compared the accuracy of air photo interpretation from panchromatic, colour and infra red false colour air photography. Most workers have had one film or remotely sensed product available to them or, at best, have been in a position to order a particular product because of prior knowledge of its effectiveness. This paper attempts to bring together information on various remote sensing products and their processing which would be relevant to vegetation science workers.

In any vegetation study the problem, or aims and objectives, must be clearly defined prior to embarking on the study, and especially before obtaining any remote sensing products. If a map is to be used to illustrate the results of a vegetation survey the amount of information to be gathered by fieldwork and from remote sensing media should be applicable to the final mapping scale. It is essential to understand the relationships and differences between the terms 'scale of survey', 'scale of mapping' and 'scale of remote sensing' (Küchler, 1967; Edwards, 1972a). The scale of remote sensing and mapping is entirely dependent on the scale of survey, which is dictated by the problem which has to be solved and how the results are to be presented. For purposes of convenience, vegetation surveys have been grouped into five major classes:

1. General and general-reconnaissance surveys
2. Reconnaissance surveys
3. Semi-detailed surveys
4. Detailed surveys and studies
5. Ultra-detailed surveys and studies
   (after, Edwards, 1972a & b, Edwards & Jarman, 1972).

It is implicit in the interpretation of remotely sensed products for vegetation mapping purposes that a classificatory process is involved (Webb, 1954). This emphasizes an important distinction between the approach of a vegetation mapper and a geologist mapping geological surface features. The geologist is trying to enhance images for *detail,* whereas the vegetation worker is aiming to simplify the detail into manageable categories — or classify ground cover types on certain criteria.

It is essential that the nature and requirement of the classificatory process being applied is clearly understood. For vegetation survey, the view taken here is that the properties of the vegetation should be the primary criteria for its classification. The chief vegetational criteria by which vegetation has been classified, singly or in combinations, are physiognomy, structure and dominance, floristic composition

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and successional relationships. Again, scale of survey, scale of mapping and scale of remote sensing product determine the classificatory process used. Non-vegetational criteria such as habitat and geomorphology are used where vegetation units may not be the prime consideration, such as in land use surveys and assessments for site potential.

When discussing scale in this paper, large scale includes scales of from 1: 20 000 to 1: 10 000 and larger, medium scale from 1: 20 000 to 1: 125 000, and small scale includes scales of 1: 125 000 to 1: 3 000 000 and smaller.

With the current availability of remote sensing products, use of which will be described in separate categories in the following account, it is highly recommended that an integrated approach to the use of remote sensing products be adopted. This implies a particular discipline and order in the collection and recording of all levels of data — from precise (co-ordinate identification) location of sample sites in the field, corresponding location of field sites on remote sensing products, choice of size of sample unit (it might well be necessary to take a series of nested samples), recognition of the level of detail to be collected at different scales, use of different products or processing throughout an area in order to emphasize different features of the area, and storage of data in a grid system which could be used by other workers in a variety of disciplines. It is also necessary that nationally acceptable and applicable classification systems should be adopted for describing extant vegetation or land cover samples. There has recently been a system devised for the structural characterization of vegetation in the Fynbos Biome (Campbell *et al.*, 1981), which has produced encouraging results when compared to vegetation map units produced by classification of Landsat imagery in the Langebaan area (Jarman & Jackson, 1981) and by Edwards (1983).

2. REMOTE SENSING MEDIA FOR VEGETATION SURVEYS

The procedure adopted in producing a vegetation map can be broken down into three basic steps: data collection, interpretation and product generation (Fleming & Hoffer, 1977). Two basic approaches to vegetation mapping are the image oriented system and the numerically oriented system (Landgrebe, 1973). Both approaches utilize data collected from a remote location. Aerial photography is usually obtained from aircraft altitudes, optimizes spatial resolution, and is recorded on photographic film. Multispectral scanner (MSS) data are recorded and stored in digital or analog format on computer compatible tapes. Temporal and wave-length characteristics are optimized and data are collected from both aircraft and satellite altitudes.

2.1 *Photo products for visual interpretation*

2.1.1 *Panchromatic prints*

South Africa has complete aerial photographic coverage in panchromatic film at scales from 1: 20 000 to 1: 75 000. These photographs are available from the Director of Trigonometrical Survey Office in Pretoria. Photographs of this type are used primarily for trigonometrical work, but have also provided a basis for most vegetation mapping carried out with the aid of remote sensing media in South Africa. Panchromatic photographs are not as efficient, or as accurate for some interpretation projects as certain other media, but these have often to be used in the absence of more suitable media. With good tonal contrast the human eye is able to distinguish 200 tones of grey.

2.1.2 *Infra-red black and white prints*

Another air photograph product in black and white print form is the modified infra-red photograph. This film is sensitive to near infra-red wavelengths (i.e. 0,83–1,1 microns) as well as the visible wavelengths, but not thermal infra-red. If only infra-red wavelengths were recorded, shadows would be black, whereas detail in the shadows is visible in modified infra-red with red and green light present and blue excluded by a filter.

Objects with high infra-red reflectance, such as plants which reflect infra-red from the cellulose cell walls (Blythe & Kurath, 1968), show up in light tones, whereas objects with high infra-red absorption, especially water, show up black, making this medium ideal for mapping vegetation in swampy areas. Black and white infra-red photography was used extensively for forest inventories in North America, before more sophisticated media became available, as the different types of timber trees could be recognized by their differing infra-red reflectance signatures (Jensen & Colwell, 1949; Schulte, 1951; Stellingwerf, 1969). Successful vegetation studies were also made using black and white infra-red photography (Ives, 1939; Schulte, 1951).

Useful qualities of infra-red films are its penetration of haze and its detection of free water surfaces which show up pitch black (Spurr, 1960). Haze penetration is of particular importance in tropical areas where atmospheric moisture decreases the clarity of normal panchromatic photographs.

2.1.3 *Colour aerial photographs*

Experiments carried out overseas produced conflicting results about the advantages gained from the use of colour prints for vegetation studies. Mott (1966), Anson (1969) and Goodier & Grimes (1970) all state that colour photography gives no added information over panchromatic photography for vegetation studies, whereas Becking (1959) and Heller *et al.* (1964) found colour to be advantageous. Goodier & Grimes (1970) suggest, however, that not enough basic research has been done to show final conclusions.

Colour has been tried and proved useful. Its major advantage lies in assisting interpreters who do not have a wealth of experience, as they are able to recognize patterns on hue as well as on textural differences and site factors, and not merely on slight tonal variations, textural differences and site factors as in the use of panchromatic products (Duddek, 1967). The eye can detect 20 000 different hue variations compared with a mere 200 tonal variations (Evans, 1948). Photo hues also correspond closely to the actual vegetation colours on the ground, which facilitates recognition of species. The disadvantages of this film type are that flying conditions, due to its inability to penetrate haze, and the processing, are more critical than panchromatic film and the cost is higher.

Colour transparencies have better resolution than colour prints (Welch, 1968) and, possibly, colours are more readily standardized as there are fewer processing steps. Transparencies, however, are inconvenient for fieldwork as they require a light table for viewing and annotation is more difficult. A field apparatus for viewing transparencies has, however, been described by Wear (1960). The major disadvantages with this product are that there is no negative master copy so that the transparencies cannot be easily duplicated.

2.1.4 *Colour infra-red*

Colour infra-red photographs, also termed 'false' colour photographs, record the same wavelengths as the black and white infra-red, but different dyes in the film are sensitive to the different wavelengths which create different hues on processing (Smith, 1968; Stellingwerf, 1969). Hues on this medium represent the following hue image features on the ground. The red image colours on the photographs represent objects on the ground with high infra-red reflectivity, such as active vegetation; ground features with red and green hues are represented by green and blue photograph image hues respectively, whereas objects with blue hues are excluded from the image by using a blue filter.

The use of the longer wavelengths improves haze penetration, which gives photo images sharp boundaries, thereby improving resolution and making this medium useful for detailed work. Because of its haze penetration properties, this film can be used to great effect in high level photography (Pease & Bowden, 1969; Pease, 1970).

Colour infra-red film has been claimed by overseas workers to be ideal for vegetation studies (Anson, 1969; Colwell, 1967; Driscoll, 1971). Anson (1969) claimed that twice the detail could be retrieved on this type than from panchromatic or even colour film. The use of this film medium is claimed by Lauer (1968) to decrease interpretation time by 25%, whereas Haack (1962), after statistical analysis was not convinced of the overall advantage of this medium. The various claims for this film type cannot be evaluated unless the particular problem for which it is to be used is clearly defined.

2.1.5 *Multi-spectral photography*

A comparatively new product is multi-spectral photography described by Yost & Wenderoth (1968) and Smith (1968). Light reflected from various objects is recorded by wavelength separately on black and white film. The separation of light into the various wavelengths is done by using a number of lenses each with a different filter combination. Pictures are then reconstituted by superimposing the different black and white transparencies. Being able to select the various wavelengths to be recorded makes this an extremely versatile medium (Malila 1968; Ross, 1971).

The multi-spectral approach has great potential for analysing vegetation and recognizing vegetation patterns, and has been used in a number of studies. The Landsat series utilizes a multi-spectral system as one of its two systems for recording data.

Depending on the scale used, this type of remote sensing can detect individual species (Weber, 1966), or make inventories of large areas (Lent & Thorley, 1969). This process is available in South Africa, but has not been used for general vegetation mapping from aircraft levels of resolution apart from brief experimental natural resource studies of vegetation.

Multi-spectral satellite products from Landsat 1, 2 and 3 in the form of single wave band black and white prints, black and white negatives, 3-band false colour composites, and 3-band false colour transparencies are all available at any suitable scale of any specified portion of a Landsat scene (185 × 185 km) from the Satellite Remote Sensing Centre (SRSC). The standard products of a whole Landsat scene (185 × 185 km) are issued as 1: 1 000 000 scale, 1: 500 000 scale and 1: 250 000 scale products (18,5 cm, 37,0 cm and 74,0 cm sizes) (Anon., 1982).

2.1.6 *Other photographic media*

Other remote sensing products include K-band radar (Morain & Simonett, 1967; Lewis & Waite, 1973) and thermal infra-red imagery (Colwell, 1967; Sabins, 1973). Neither of these have been successfully applied to vegetation mapping and appear better suited to geological applications.

The 1: 10 000 black and white ortho-photo product produced by the Directorate of Trigonometrical Survey is also available for specific areas. These are maps produced from 1: 30 000 scale black and white photos. They are paper products, not available as stereopairs, but have contour intervals of 5 m drawn in on them. For areas where they are available, they are an asset to field location of sites and are generally a practical product to use in the field.

2.2 *Digital imagery for computer-aided analysis*

The international emphasis in the use of remote sensing imagery for mapping purposes has swung away from purely visual or image oriented interpretation of data, to numerical, computer assisted classification techniques. These fall within the general heading of digital image processing.

Image processing can be regarded as any operation carried out on an image once it has been recorded on some medium. Recording of spectral reflectance from a portion of the electromagnetic spectrum in digital form allows for flexible manipulation of data with the aid of computer processing techniques. Digital image processing comprises three main branches:

1. Image restoration processes which recognize and compensate for data errors, 'noise' and geometric distortion introduced in the scanning and transmission processes.
2. Image enhancement processes which modify an image in order to alter impact on the viewer.
3. Information extraction processes which utilize the decision making capability of computers to

identify and extract specific groups of information (Sabins, 1978).

Visual interpretation of imagery in the form of photo products is equivalent to information or feature extraction processes when applied to digitally stored spectral information.

The information extraction processes use computer classification techniques on two or more bands of multi-special scanner (MSS) digital data. Processing of the multi-band image is made possible by recognizing and classifying the spectral signatures in their numerical form. Each picture element (pixel) is assigned to a specific class by matching the spectral signature with the range of signatures determined for the class. The preprocessing leading up to the classification is geared toward locating and identifying representative groups of signatures, called training classes, and ensuring that they are sufficiently different to prevent confusion among them. This type of pattern recognition in digital image processing is statistical in character, and includes 'statistical space' in which the 'pattern' is a vector made up of a number of measurements in an n-dimensional space, where n represents the number of MSS bands utilized. The pattern recognition system seeks to partition or place boundaries in the n-dimensional space so that each region of the image can be assigned to a class of patterns (Hajic & Simonett, 1976). A mosaic of the image may thus be simplified into n manageable number of relatively homogeneous spectral classes.

2.2.1 *Landsat computer compatible tapes*

Since January 1981, Landsat imagery has been directly received in digital form on computer compatible tapes (CCT's) at Hartebeeshoek Satellite Remote Sensing Centre. Digital imagery dating back to 1972 when the first Landsat satellite (ERTS−A) was launched is also obtainable from the Satellite Remote Sensing Centre and from NASA. MSS Landsat data are recorded in four bands on computer compatible tape for the pixel units (picture element 56 × 79 or 0,44 ha). The wavelengths of the bands are:

Band 4 (Green)	0,5−0,6μ
Band 5 (Red)	0,6−0,7μ
Band 6 (near 1 R)	0,7−0,8μ
Band 7 (near 1 R)	0,8−1,1μ

Processing of this digital imagery is being carried out for vegetation, land cover and land use mapping purposes at the Satellite Remote Sensing Centre; at the National Physics Research Laboratory (NPRL), Council for Scientific and Industrial Research (CSIR), using the VICAR system on an IBM system 370/158 (Fink & Van Zyl, 1977); at the University of Cape Town on a UNIVAC 1100 Model 18 Computer (Anon., CATNIPS and NEWPIPS); and at the University of Natal on a UNIVAC Computer (Anon., NEWPIPS).

2.2.2 *Digitized air photos*

The Satellite Remote Sensing Centre has facilities for digitizing standard air photos on request. This is done by scanning the photo with a scanning microdensitometer and recording the grey scales from black and white imagery, or colour intensity on other imagery in digital form. Scogings & Ward (pers. comm., 1981) are involved in a vegetation study of the Kuiseb River region, using imagery which has been processed in this way. All the techniques of digital processing carried out on Landsat products are relevant to these digitized products. They provide a superb interface between satellite imagery and air photos, and between visual interpretation and computer analysis feature extraction processes.

3. SEASON OF IMAGERY — TIMING OF PHOTOGRAPHY

As maximum information on remote sensing imagery is associated with maximum contrast on the ground, remote sensing products should usually be made at the time of maximum vegetal contrast on the ground. This time of contrast varies, depending on climate and structure of the vegetation.

In grassland in South Africa, maximum contrast in the visible wavelengths would be in the autumn period of March, April and May, when the different grass species take on their autumn colours prior to being bleached by the winter climate. Similar results are reported by Driscoll (1971) in America. The exact time for ideal photography will, however, vary from year to year depending on local variation in the rainy season.

If it were necessary to take the imagery at a less favourable time, such as during mid-summer when all grasses appear a uniform green, it is possible to change the remote sensing medium from, for example, colour prints to infra-red colour prints, or to multi-spectral photographs where the difference in species could possibly be detected using additional infra-red wavelengths or a particular section of the electromagnetic band. If, however, the aim were to detect shrubs and trees in open woodland, remote sensing products should be made when contrast between shrubs and trees and grass is maximal, which would probably be prior to the trees losing their leaves, when perhaps the grass is dying back, or after the first flush of spring, when the tree leaves are green, but the grass still has its winter yellow colour.

Repetitive imagery from Landsat 1, 2 and 3 has shown the effect of seasonal change in obscuring or enhancing certain patterns in the landscape. In summer imagery over the summer rainfall region of South Africa, vegetative growth masks certain cultural features, yet enhances some geological features. In winter, evergreen vegetation is clearly separated from seasonal vegetation, whereas in summer the differences are less marked due to lower contrast. The timing of imagery is therefore dependent entirely on the aim of the particular project.

Work by Jarman (1981) on digital Landsat imagery in the Langebaan area, and by Lane (1980) on digital Landsat imagery in the Verlorenvlei area, has revealed an interesting aspect of the importance of seasonal variation. With good cover (>70% projected canopy cover) for West Coast Strandveld

(Acocks's Veld Type 34) communities in the Langebaan area, summer imagery provides greater distinction between the drought deciduous elements (losing leaves in summer) and the evergreen elements. However, further north at Verlorenvlei, as the ground cover drops to values of 5–25%, summer imagery containing the drought deciduous elements gives no distinction from the background soil characteristics. It would appear that in the lower cover categories (below 50% ground cover), the time of maximum leaf standing crop is the best time for vegetation mapping. In good ground cover areas (>50%) the time of maximum contrast between dominant elements should be chosen.

Time of day at which imagery is taken is also important. Careful selection of sun angles can utilize shadow to enhance features. Photographs taken at midday in some areas can also introduce a haze problem. The Landsat satellite orbit is sun-synchronous and the satellite passes over a particular area at the same time of the day at each pass. However, throughout the year, the sun angle is changing all the time. Repetitive Landsat imagery, therefore, can reveal or enhance certain features because of the changing sun angle. This is an advantage when it comes to enhancement for feature extraction purposes, but a disadvantage when change detection is the main objective.

4. SCALE OF SURVEY, SCALE OF MAPPING AND REMOTE SENSING

Küchler (1967) stresses the relationships between the scale at which the survey is planned, the final mapping scale and the scale of suitable remote sensing products. Different scales of survey will detect different types and sizes of vegetation pattern. The survey scale hence indicates the degree of precision at which the vegetation is studied, recognized and described. Table 1 is not intended as a rigid system, but is a suggested system relating these three factors. The major groups of scales of survey with their inherent restrictions as to field methods of vegetation analysis and scale of remote sensing products are presented.

Scale of remote sensing products is usually larger than the mapping scale. The remote sensing product contains more information than is actually required on the map. The scale difference is in order to make boundaries as accurate as possible. It does mean, however, that for mapping much of the information on the remote sensing product has to be classified into major types to make the map easily intelligible.

The classing of survey scales given in Table 1, based on Edwards (1972b), is one of many similar classifications. However, it has been designed for specific use in South Africa. It is appropriate to visual interpretation of photo products. Table 2 (from Jarman, Bossi & Moll, 1981) relates to the use of computer classification procedures as applied to Landsat digital imagery. It gives a breakdown of selected scales of mapping based on Table 1, giving the minimum size of map unit recognized at each scale and what this means in terms of the number of pixels involved in classification in each instance.

In the Jarman, Bossi & Moll (1981) study involving computer classification of digital data it was decided to limit investigation to four scales of operation, namely:

1. detailed (1: 10 000)
2. semi-detailed (1: 20 000)
3. semi-detailed (1: 50 000)
4. reconnaissance (1: 250 000)

These four scales of operation were selected because of the availability of maps, standard air photo products, and orthophoto products at these scales.

TABLE 1.—General relationship between scale of study, scale of mapping and scale of remote sensing product using visual interpretation techniques (after Edwards & Jarman, 1972)

Scale of survey	Aim	Final map product scale	Appropriate air photo	Appropriate field sampling procedures
General and General Reconnaissance	Ascertain major classes of vegetation at regional and sub-regional landscape levels	1: 1 000 000 or smaller	1: 500 000 – 1: 1 000 000	Descriptive, non-defined, non-regular samples usually recording physiognomic types
Reconnaissance	Determine the main plant communities/ecological relations within regions or sub-regions	1: 50 000 – 1: 1 000 000	1: 40 000 – 1: 500 000	Non-regular samples, low density of plot samples recording structural types and dominant floristics
Semi-detailed	Investigation of physiognomic /structural and floristic structure of communities and habitat relations	1: 10 000 – 1: 50 000	1: 5 000 – 1: 20 000	Defined samples, moderately high density, recording structural types and total floristics
Detailed	Study of structure and function of community or part of community	1: 500 – 1: 10 000	1: 5 000 or larger	Intensive quantitative sampling on defined plots
Ultra-detailed	Study within community species/species group / habitat relations	1: 500 or larger	1: 500 or larger	Intensive quantitative sampling on defined plots/ species

TABLE 2.—Relationships between map scale, smallest recognizable map unit (in ha) and number of spectral units used in numerical classification of digital remote sensing data (from Jarman, Bossi & Moll, 1981)

Final map scale	Smallest map unit recognized = 2 print characters		Units used in digital classification	
	No. of pixels	(ha)	No. of pixels	(ha)
General and general reconnaissance >1: 1 000 000	3 200	1 408,0	1 600 (40 × 40)	704,0
Reconnaissance 1:250 000	200	88,0	100 (10 × 10)	44,0
Semi-detailed 1: 50 000	8	3,5	4 (2 × 2)	1,8
1: 20 000	2	0,8	1	0,4
Detailed 1: 10 000	1	0,4	1	0,4
Ultra-detailed <1: 500	Beyond the limits of resolution of current Landsat series			

4.1 *General and general reconnaissance surveys*

The purpose of these surveys is to ascertain the major classes of vegetation at regional and sub-regional landscape levels and the main climatic, soil and biotic relationships (biomes). Major extensive functional processes prevailing in the ecosystems involved, such as the main plant successional trends, or retrogressions, leading to prevailing climax, sub-climax and disclimax types would be identified. These surveys are based on either general observational data or on indeterminate stand data, that is, sample plots without a specific size, such as those in Acocks's method (Acocks, 1975). Mapping scales used to show the distribution of vegetation are at 1: 1 000 000 or smaller. The value of such surveys is for general and regional planning and for determining problem areas requiring further investigation. The map products would be prepared for those in the planning and administration levels.

For such surveys the obvious choice of remote sensing scale to detect the main landscape vegetation patterning is small, of the order of that obtained by high altitude, ultra wide angle photography and satellite imagery. Photo scales used are therefore 1: 500 000 or smaller.

At these scales, stereoscopic coverage is often not possible. The Landsat Return Beam Videcon and MSS do overlap sideways sufficiently for stereoscopic viewing (Lintz & Simonett, 1976). Stereoscopy at this scale, however, is often not required as these images are required only as mosaics.

The remote sensing medium, by nature of the distances involved between 'sensed' surface and recording surface, must be highly sophisticated, and the accepted forms are multi-spectral imagery as well as active and passive radiometric methods, of which the images may be displayed in the form of a computer print-out.

The application of computer classification techniques to compress Landsat digital data at this scale would not be suitable. Compressing information into 40 × 40 pixel blocks at a 1: 1 000 000 scale of operation would lose too much information (Jarman, Bossi & Moll, 1981).

Maps resulting from these surveys, at scales of about 1: 1 000 000, cover large areas and delimit major vegetation types. The usual approach to this type of mapping would be either from combining information from larger scale maps or from photographic images at extremely small scales, such as the photographic imagery from Landsat 1, 2 and 3, which is commonly available at a scale of 1: 1 000 000.

The only vegetal detail to be considered at this level would be gross physiognomic types, which are often associated with major geographical divisions as expressed by Drued (in Cain & Castro, 1959) for example, equatorial forests and monsoon forests, or recognizing only the vegetation formation types like forest (Fosberg, 1961). These vegetation maps are not based on detailed fieldwork. African maps produced for these purposes include the AETFAT Vegetation Map of Africa, South of the Tropic of Cancer (Keay, 1959), at a scale of 1: 10 000 000, and a map at a scale of 1: 4 000 000 by Pole Evans (1936) of the Vegetation of South Africa.

The best known map of the vegetation of South Africa is that by Acocks (1975) at a scale of 1: 1 500 000. This map represents an exception to the general rule for surveys at these scales, as the vegetation classification is based on floristic data and site type criteria from 'samples' which provides unusual detail at this level of survey. On every landscape type, or area within the same farming potential Acocks (1975) recorded all the species present and their abundance, and on this his Veld Types were based. In this case, the information was initially mapped at 1: 500 000 and then reduced to 1: 1 500 000 to give a more concise picture and a more practical and manageable map.

4.2 *Reconnaissance surveys*

The purpose of these surveys is to redefine and confirm more accurately the main classes of vegetation established by the general surveys, but specifically to determine the main communities. Ecological relationships in terms of habitat and biotic relations, and the functional community processes such as plant succession, are investigated in greater detail for the main plant communities. Such surveys may be based upon lists of species from non-defined samples, or on a low density of sample plots within the main community types that are defined by relatively gross physiognomic, floristic and ecological criteria. Mapping scales are from 1: 1 000 000 to 1: 50 000. Appropriate air photo scales for visual photo interpretation in such surveys are between 1: 40 000 and 1: 500 000, obtained from fairly high altitude and wide angle air photography. At the smaller scale, stereoscopic cover is not necessary, but at the larger scales it becomes desirable to assist in more detailed interpretation.

The photographic products of small scale vary from sophisticated satellite-borne media, such as multi-spectral imagery and radiometric methods, to infra-red false colour for high-level photography (scale 1: 150 000). The only larger scale photo products, which have until recently been available, are panchromatic film or infra-red colour photography. Colour photography is not usually recommended due to the problem of haze penetration making colour photography impractical.

In areas where cloud cover is virtually continuous and atmospheric moisture level is extremely high, as in Nicaragua (Crook & Kyle, 1972) and Panama (Crandall, 1969) in Central America, radar has been used as a remote sensing device which can penetrate cloud to give imagery for this scale of survey.

Use of computer classification procedures of feature extraction on digital imagery at this scale of operation is ideal. Compressing the spectral information to a 10 × 10 pixel matrix, with each unit used in the subsequent processing being 44,0 ha in extent, results in a line printer map product which is approximately 1: 250 000 in scale. This is an ideal scale for operation due to the availability to all potential users of 1: 250 000 Topographic and Topocadastral series produced by Trigonometrical Survey for the whole of South Africa.

Jarman, Bossi & Moll (1981) found that the reconnaissance scale of operation best utilizes the digital satellite data, as the classification routines involved compress the spectral information into manageable proportions. The returns on time and the amount of field control work necessary to produce a satisfactory classification are good.

The final map product of this scale of survey is between 1: 1 000 000 and 1: 50 000, whereas remote sensing products would be at scales of 1: 500 000 to 1: 40 000. This would require a reduction in scale of between 10 and 2,5 times from the remote sensing image to the map.

The classification of vegetation used here remains general with divisions on gross criteria such as major physiognomic formations being recognized, together with qualifying floristic data in terms of major dominance types. This type of mapping has been used extensively in areas where basic resource surveys of developing countries were required to enable initial apportionment of an area for efficient land utilization.

The field information required to produce maps of this type is based on a low density of actual samples. This means that communities recognized have a type situation where some method of vegetation analysis was applied and a number of these type situations were grouped to give a vegetation classification. The community type is then associated with its aerial photo image and, often, a site type, and an overall picture is obtained of the vegetation by annotating recognizable vegetative communities. This scale of survey is carried out by the Directorate of Overseas Surveys, United Kingdom (Aitchison *et al.*, 1972), with vegetation communities such as *Acacia raddiana* tree and shrub savanna, *Boswellia* Woodland/Tree savanna, being recognized.

This scale of survey has not been much used in South Africa, possibly as air photography in South Africa was, until the late 1950's, taken at scales of 1: 20 000 and 1: 30 000 only. Acocks's (1975) vegetation map, although published at a scale of 1: 1 500 000 and therefore grouped as a General or General Reconnaissance Survey, contains detail sufficient to be classed as a Reconnaissance Survey.

4.3 *Semi-detailed surveys*

These have the objective of discerning, defining and investigating vegetation upon the basis of the plant community. The physiognomic and floristic structure of the community and its habitat are determined by analysing circumscribed sample plots. Mapping of the plant communities is at scales from 1: 10 000 to 1: 50 000. This corresponds approximately to the medium scale of the Directorate of Overseas Surveys, which recognizes scales from 1: 25 000 to 1: 125 000 as the medium scale limits, but with an emphasis on 1: 50 000 (Read *et al.*, 1973). These surveys are of major importance in defining, classifying and studying community and habitat relations from quantitative or semi-quantitative data. They provide also the main classificatory reference framework for ecosystems from which the extrapolations and predictions provided by more detailed studies can be made. They are the type of survey upon which most management procedures of an area are based. Appropriate air photo scales for such surveys are from 1: 5 000 to 1: 20 000, for upon these air photograph scales can be determined the various plant communities, and measurement of vegetation density and cover can be made with reasonable accuracy appropriate to the scale of survey. However, where such photo scales are not available, use can be made of 1: 30 000 to 1: 40 000 scale photos for devising appropriate sampling strategies and tactics, as well as for the final mapping of the vegetation.

The main remote sensing product used in the past was panchromatic prints. This level of survey is, however, ideally suited to colour photography.

The emphasis in this scale of survey is on a moderately high plot sample density which records vegetation pattern at an Association level (Shimwell, 1971), and air photos are important in all phases. As they are especially important in the field, positive transparencies are impractical.

Stereoscopic coverage is essential at this level of survey to increase accuracy of visual interpretation and, thereby, use of the imagery to its maximum advantage.

There are a number of classification methods which may be used to group vegetation into classes at this scale. The methods most commonly used are physiognomic and dominance type ones similar to the previous survey scale, but the pattern of vegetation recognized is finer. Floristic methods too, such as those of the Braun-Blanquet approach, may be applied effectively to classify the vegetation. Computer classification techniques applied to Landsat digital imagery can be utilized at this scale of operation, but must be based on good ground truth and precise location of samples using ground control points. One of the benefits of digital Landsat imagery is its versatility when it comes to scale of operation. It can be used from a map scale of 1: 20 000 to 1: 250 000, and the units of resolution can be adjusted to meet the requirements of each scale of operation. At a semi-detailed level of investigation single pixels are used as classification units (Jarman & Jackson, 1981). These techniques were applied with some success at a semi-detailed level of investigation in the Langebaan area (Jarman & Jackson, 1981). In this study, the map units defined were structural units and not floristic ones.

Computer classification of digitized standard air photo products would be more appropriate to this level of survey, since the floristic differences which are not readily discernible from satellite imagery become so on air photo products of 1: 20 000 and larger.

4.4 *Detailed surveys*

These have the purpose of studying in detail the structure and functioning of one or more of a group of closely related plant communities (or ecosystems). Such surveys are based on intensive quantitative sampling of vegetation and environment and mapping is at scales larger than 1: 10 000. The results of these surveys can be extrapolated and predicted on the basis of the classificatory reference framework provided by the semi-detailed and coarser surveys.

Air photograph scales that are used must be larger than 1: 5 000 so as to allow species of trees and large shrubs to be recognized, measurements of heights, density and cover of the strata plants to be made, and large scale mapping to be done.

This scale of survey provides the largest range of possibilities for using remote sensing techniques. Standard panchromatic and colour prints may be used for a synoptic view, fieldwork, and orientation with a particular area. For better definition, positive transparencies, especially of the infra-red colour type, may be used. Enhancement of certain features requires multi-spectral photography. Radiometric methods, such as radar, may also be used. These methods provide information in various forms, especially computer compatible tapes, but thus far have not often been used.

The scale requirements of the various products are varied and the platforms required to raise the remote sensing instruments vary from aircraft, helicopters, balloons (Rosetti, 1963; Whittlesey, 1970) to booms and ladders (Whittlesey, 1966; Pierce & Eddleman, 1970). In the other survey scales vertical and stereoscopic products of remote sensing are required to give photogrammetrically correct images, but in detailed work some recordings may be made from oblique angles where, although scale is variable and stereoscopy often not possible, the desired detail is obtained (Harris & Honey, 1973).

The object of carrying out detailed surveys is usually not merely to record the position of plant communities, or individual plants, depending on the particular scale, but to study community or individual form and function. There are usually other measurements required and the map is merely to record where and in what state the vegetal components are at a particular time.

Methods of studying and classifying vegetation are often quantitative at this level of investigation, though other methods such as the Braun-Blanquet approach can be used, provided the desired pattern of vegetation is reflected in the communities recognized.

Although computer classification of Landsat data can be carried out at these levels, using single pixels as classificatory units, it is at the limit of resolution for this imagery.

Again, the digitization and classification of air photoproducts would be more appropriate.

4.5 *Ultra-detailed surveys*

These surveys consist of detecting patterns of within plant community species groups, sociability ratings, microhabitat species specificity, and microhabitat structural or functional relationships, phenological studies, linking to ecophysiological approaches, biomass estimates, etc. Remote sensing platforms are essentially groundbased, e.g. tethered balloons, frames, ladders, etc., and ground sampling is intensive and quantitative. Succession can be monitored after fire, and measurements are made directly off the photos. Stereoscopy is helpful for direct measurements off photos. There are techniques for taking vertical pictures from directly above as well as at right angles to the sample site from which measurements can be made (Adams, pers. comm., 1981). Imagery is not used in ultra-detailed studies to the degree that it should be. As a permanent record at a particular time, it cannot be bettered.

5. MONITORING VEGETATION CHANGE

The objectives of vegetation monitoring must be well defined so that appropriate choice of techniques can be made. For instance, it is necessary to know what must be measured and what degree of detail and precision is required: height, cover, density, or productivity of dominant or certain species, growth form, community or regional changes, or small sample plot changes. The regularity of recording and imagery to meet these requirements must be ascertained, i.e. when and how often should measurements be made? Finally, careful consideration must be given to what ground observation requirements for calibration and verification are necessary in order to make the appropriate choice of remote sensing product and interpretation technique.

Once the objectives have been defined, the appropriate scale of operation can be selected and the appropriate remote sensing product motivated for. Monitoring something like normal regional habit change would require, for example, Landsat imagery taken at yearly intervals. Monitoring incidence of and extent of fires on a regional basis would require at the minimum seasonal coverage, and preferably coverage as regularly as it becomes available during the fire season. At the theoretical best this is once every eighteen days for Landsat imagery.

At the scales for which processing of digital Landsat data is best suited (1: 50 000 to 1: 250 000), provided the various programme parameters are kept constant and cloud cover percentage controlled, once a scene has been processed for one date, change can readily be detected on subsequent dates. It is not necessary to define what the change is in terms of precise detail, but to identify where it is for field checking. Work done in the Langebaan area has shown the strong link between plant community height, canopy cover, type of substrate and spectral map class (Jarman, 1981). Incidence of normal successional changes in plant communities will not be easy to detect, but the incidence of dramatic changes in canopy cover and height of dominant strata due to accelerated erosion, fire, brush-cutting, clearing of areas for development, etc., will be readily monitored.

6. AVAILABILITY OF IMAGERY

The importance of this cannot be sufficiently stressed. In South Africa, imagery available to all users not requiring special motivation is the standard black and white panchromatic product produced by Trigonometrical Survey. For its own purpose of mapping the country at a scale of 1: 500 000, the office of the Director General of Surveys plans to cover the Republic with panchromatic photography at a contact print scale of 1: 50 000 in approximately ten year cycles. The first cycle was initiated in 1971. They are currently also conducting experiments with 1: 150 000 photography for the purpose of monitoring changes. Depending upon the nature and scale of changes detected, it will be decided whether or not additional second cycle photography at 1: 50 000 is required. This means that areas subject to rapid development will probably be re-flown at 1: 50 000 earlier than static areas, and ultimately of course, more often.

Other photography is organized and supervised by the Director General of Surveys on the following basis:

1. Areas for which orthophoto mapping has been requested and approved are flown at 1: 30 000 specifically for the production of the orthophoto maps, at a scale of 1: 10 000;
2. Black and white photography requested by other Departments, such as the Department of Agriculture, is normally flown at a scale of 1: 30 000 or 1: 40 000;
3. Special jobs at other than the scales mentioned above and including colour photography are considered individually and treated according to merit.

The whole air survey programme, including both photography required for the Director General of Survey's own mapping work and that requested by other Departments, is considered by the National Advisory Survey Committee. The size and content of the programme approved by the committee depend largely upon available funds, and the motivations submitted by other departments.

As can be seen from the foregoing, it is most unlikely that the major established conservation areas will be included in areas flown on a *routine basis*, because by their nature they are areas of zero, or very limited, development or change. The scale of routine photography (1: 50 000 or 1: 150 000) has so far been of relatively limited value for interpretation and mapping of vegetation and even for transfer to base maps at 1: 50 000 (Bands, 1978).

The availability of Landsat imagery, prior to direct reception by Hartebeesthoek Satellite Remote Sensing Centre was sporadic. Within the study carried out on Fynbos Biome mapping, of the 15 Landsat images needed to cover the whole Fynbos Biome geographic area only 12 were available for the whole of the 1972/73 period. (Bossi, pers. comm., 1981). It was not possible to investigate either monitoring of habitat change or effects of season on vegetation mapping from the available imagery in the investigation carried out by Jarman, Bossi & Moll (1981). Even with direct, regular reception, availability of imagery remains a problem. Cloud cover is a problem, especially along coastal and mountainous areas. Fraser & Curran (1976) report on two hypothetical satellite survey missions in which the success of the first mission requires at least one observation of the entire 185 km^2 field of view without cloud, and the second permits viewing whatever cloud free areas exist. On successive satellite passes new cloud free areas may appear, and a mosaic of the field of view can thus be assembled. The result of this theoretical exercise showed that the entire field of view could be seen on mosaicing with high confidence after 7 satellite passes, whereas the entire field of view could be seen with only 50% probability after the same number of passes. For a 90% probability of success 22 passes were needed. This emphasizes the importance for informed national integrated planning when motivating for adequacy of scale of product and regularity of recording of imagery to be used in vegetation monitoring and seasonal studies.

7. MAP PRODUCTION

It is not intended to deal in any detail with the variety of photogrammetric instruments and approaches to cartography available to vegetation mappers. It suffices to say that the development of map categories, consistent identification of photo units in visual interpretation, and subsequent transfer of information on to a map presents the biggest obstacle to most workers. More often than not, maps are not produced.

At the larger scales in semi-detailed work, tying large scale air photo products to digital processing at the map production stage is, therefore, a very practical solution. It is also suggested that establishing contact with photogrammetric and cartographic units with professional assistance at this stage saves time and money in the long run. Computer classification of digital imagery has the advantage that map production is part of processing. Products can be viewed or photographed off TV screens, can be in line printer output form with suitable correction to scale as part of the processing, or can be in photo print form from computer optronics output. Again, the latter can be produced at any desired scale.

8. SYNOPSIS OF AN INTEGRATED APPROACH TO VEGETATION SURVEYING AND MAPPING

The approach to the use of remote sensing products for vegetation mapping can be broken down into three basic steps: data collection, interpretation and product generation. Developments in the techniques involved in interpreting imagery have tended to polarise the approaches into either image oriented approaches or numerically oriented approaches. Fig. 1 from Fleming & Hoffer (1977) shows the interrelationships between the image oriented and numerically oriented system and the possible links between the systems.

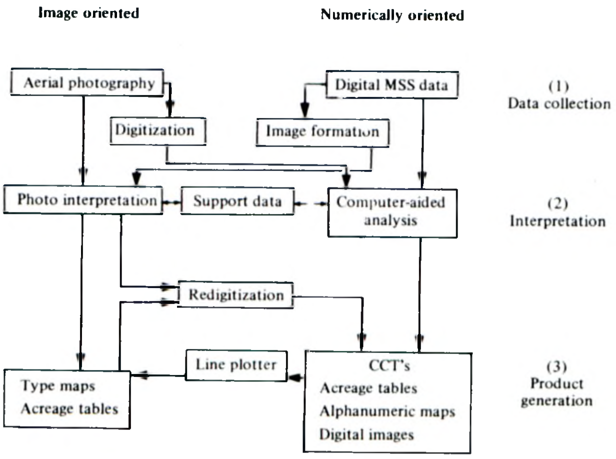

FIG. 1.—Interrelationships between the image oriented and numerically oriented system and the techniques of going from one system to the other (after Fleming & Hoffer, 1977).

Although both approaches utilize data collected from a remote location, the characteristics and format are different. The first step of data collection is covered in Section 3, which describes the products available to vegetation mappers either as aerial photographs and digital products. At the second step different approaches are used. Photo interpretation relies on trained interpreters to do the analysis by identifying and delineating the various vegetation types. Computer aided analysis techniques replace the repetitive steps of identification and recording of decisions with a computer, thus reducing bias and increasing speed (Bauer, 1976).

The third step in both approaches is dependent on the feature extraction process. Product generation for the image oriented approach entails producing a map by transferring boundaries from annotated photo-units onto a base map. Areas of features of interest are measured using dot grid or planimeter techniques.

In the numeric approach, the interpretation is recorded on CCT's as the decisions are made. Alphanumeric maps, digital images and estimates of map class areas are produced by computer algorithms that summarize data from the CCT's.

Fig. 1 shows the interrelationships between the two approaches. Aerial photography can be digitized by a scanning microdensitometer to convert the photographs to a digital format. Conversely, digitized photographic or MSS data can be converted to an image on a TV screen or on photographic film. Once data have been displayed, interactive systems allow for interpretation, redigitization and storage on CCT's. Map products from visual interpretation techniques can be digitized, stored and handled on CCT's (Boyle 1972a & b). The reverse can also be achieved in that digital information can be presented as line type maps on a plotter system.

It is recommended that the best aspects of both approaches be utilized in a fully integrated approach to a mapping problem.

9. CONCLUSIONS

Plants are a measure of the conditions under which they grow and act as an index for soil and climate. The fact that changes in vegetation occur is visible proof of the dynamic nature of the environment. It is necessary to be able to record and follow vegetation changes in order to predict and determine and control any changes which could severely upset the desired balance.

Various scales of surveys are required to provide planners with a complete picture. Small scale surveys at the general and general reconnaissance levels provide pictures of the overall situation and modern satellite imagery can quickly and effectively monitor changes.

Regional surveys provide the information for broad policy determination and planning for areas which have similar problems.

The semi-detailed survey provides for resource management planning even down to the farm level.

Detailed surveys include studies of ecosystems. Knowledge of the structural and functional attributes of ecosystems provides the means whereby appropriate ecosystem management can be devised by the pasture or other applied scientist. The role of vegetation mapping is therefore of major importance.

Remote sensing products are desirable for most surveys at any scale. The advantage of having remote sensing products is that they provide a permanent record of a situation at a particular time. Differences may then be plotted over a number of years if so desired. Certain areas which are inaccessible by normal transport and areas of this nature can best be surveyed using remote sensing techniques. In other areas, although it is possible to work without remote sensing, the rate of progress would be slower and boundaries would be less accurate than those given by the synoptic view. The time and effort saved in fieldwork offsets the additional cost of acquiring imagery.

Remote sensing products are therefore almost essential for survey work. Their use, however, should be restricted to situations where the information required can actually be obtained using this approach.

10. ACKNOWLEDGMENTS

The staff of the Ecology Section, Botanical Research Institute, over a period of years are thanked for stimulating discussion. Financial support from the CSIR National Programme for Environmental Sciences within the Fynbos Biome Project and the CSIR National Programme for Remote Sensing is acknowledged and appreciated.

UITTREKSEL

Effektiewe gebruik van afstandswaarnemingstegnieke vir die kartering en monitering van plantegroei, is 'n funksie van skaal, resolusie, afbeeldingsseisoen, soort plantegroei, sensoriese en spektrale sensitiwiteit, verwerking van die afstandswaarnemingsproduk en spoed en noukeurigheid waarmee inligting oorgedra word op die karteringsproduk.

Die soort van afbeelding, tipe van data en algemene verhoudings tussen skaal van studie, skaal van kartering en skaal van afstandswaarnemingsproduk wat van toepassing is op die Suid-Afrikaanse situasie vir visuele en digitale ontleding, word aangebied. Die tipe van afstandswaarnemingsproduk en verwerking, die toepaslike veldwerk en die doel waartoe kaarte op elke skaal geteken word, word bespreek. Gebrek aan herhaaldelike afbeeldings tot op datum, het nie voorsiening gemaak vir die volledige ondersoek van moniteringspotensiaal nie. Versigtige beplanning op nasionale vlak word benodig om die beskikbaarheid van afbeeldings vir moniteringsdoeleindes te verseker. Kaartproduseringsprosesse wat vinnig en akkuraat is, behoort benut te word. 'n Geïntegreerde benadering tot die opname en kartering van plantegroei wat die beste eienskappe van beide visuele en digitale verwerking insluit, word vir gebruik aanbeveel.

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