REMOTE SENSING APPLICATIONS IN PASTURE ANALYSIS

G. Ross COCHRANE
Department of Geography, University of Auckland

Abstract

Photographic, optical, electronic and digital methods are available for using Landsat data in applied problems of pasture surveys at a range of scales. The most versatile technique involves three stages of analysis: satellite data, aircraft photography, and field surveys.

INTRODUCTION

PASTURES are probably New Zealand's most valuable national resource. It is important to have as full and complete information about these as is possible. Details of area covered, regional variations, composition, vigour, seasonal productivity, influences of management policies, problems of pastures on drought-prone soils, and of pests and weeds should be known at national, regional; county, local, and individual farm scales for optimum planning, management and production. Ultimately, the most detailed information can only be achieved from measurement at field level. Several papers discussing pasture analysis techniques in this issue clearly illustrate this point. At the opposite extreme, broad synoptic surveys of pasture areas, gross floristic composition, regional differences, seasonal variation in growth and soil influences upon pastures — all recognizable from satellite (Landsat) imagery — provide other parameters. A range of analytical procedures using Landsat data can provide additional and more detailed information to the above.

REMOTE SENSING ,

It is not practical or economic to obtain all information at the field level. Remote sensing has the potential for monitoring pasture areas for rapid and continuous or repetitive assessment. This can best be achieved using a three-tiered sampling model embracing' (1) orbital satellite imagery at small scales (1: 1 000 000) but covering large areas at the same time; (2) substage aircraft photography of representative selected sample areas at much larger intermediate scales (c. 1: 15 000) ; and (3) ground measurement at sample sites within the former for the most detailed studies to calibrate spectral reflectances with pasture composition, productivity, vigour, incidence of disease or other physiological stress, role of management, influence of fertilizers and soil conditions, or other relevant factors.

Remote sensors, such as satellite multispectral scanners and aerial single lens and multispectral cameras, record reflectance of electromagnetic energy from pastures and other landscape features. Such reflectance from pastures is a complex integrated response from the plants and the soil background.

Although pasture areas are often less heterogeneous than many other landscapes, pasture analysis ,is complex because of the characteristics of soils, and because pastures are dynamic with constantly changing conditions — e.g., grazing management, seasonal weather, soil moisture, soil nutrient status, and mineral availability. Remote sensing applications attempt to interpret the variety and complexity through an understanding of plants and soils and their interactions with the electromagnetic spectrum (Knipling, 1969; Gausman et *al., 1969;* Gates, 1970) .

AERIAL PHOTOGRAPHY

A broad range of information at a different level of generalization from both the ground and satellite surveys is available at intermediate scales from aircraft. This can be obtained as single lens panchromatic (black and white), black and white infrared, colour, colour infrared,. or as multispectral photography embracing any combinations of these.

Panchromatic vertical aerial photography has been used for a long time, on an operational basis, for mapping pasture areas and for allied surveys. More recently the use of colour vertical aerial photography has proved valuable for detecting serious outbreaks of grass grub infestation more definitively and more readily than is possible with panchromatic photography. Colour aerial photographs at a scale of 1:2500 of the Kaahu Valley, Whakamaru area of the Central Volcanic Plateau clearly show healthy pasture and infested areas and that control can be achieved by cultivation on ploughable areas. Such photos have helped show, also, that "islands" of infestation on steeper grassed slopes remain as sources of infestation. These areas require different treatment for control or eradication (Fig. 1).

Although colour aerial photography has been long known overseas and widely used at large scale (1: 2000) to intermediate scale (1: 15 000) on an operational basis (Smith and Anson,

FIG. 1: *Part of a large scale (1:2500) colour aerial photograph of the Kaahu Valley, Whakamaru, showing the great detail and the value for interpretation purposes of the wide range of subtle tones present in the pastures, the soil and the grass grub infected areas. Much of this information is lost in the grey tones of conventional panchromatic aerial photographs. (Photo: N.Z. Aerial Mapping C2534 D/11.)*

1968) it is used chiefly as an experimental tool in New Zealand and is not yet widely adopted on an operational basis. This is unfortunate as a large range of information shown in colour tones is often masked in a smaller range of grey tones on panchromatic photographs. Flying costs for acquisition of panchromatic and colour aerial photography are not greatly different. The major increase is in colour printing costs. However, the advantages gained from 'the increased information present on colour photography frequently offsets its higher price (Cochrane, 1968, 1970).

Limited studies using aerial colour infrared photography in New Zealand have demonstrated the value of this analytical technique for detecting pre-visual stress symptoms in pasture plants and for sharply delimiting grass grub and allied pasture infestations (Cochrane, 1972) . Because of the "false" colours and the high reflectances of grasses and clovers in the near infrared spectral wavelengths (0.7 to 1.0 μm) subtle differences in pasture composition and changing seasonal vigour can be more readily determined than with either colour or panchromatic photography (Carneggie *et al.,* 1974; Bowden, 1975).

LANDSAT IMAGERY

Since July 1972, a new dimension for large-area synoptic surveys of pastures has been provided by digital and photographic data from the National Aeronautical and Space Administration (NASA) Earth Resources Observation Satellite (EROS) Landsat multispectral scanner (MSS). (Cochrane, 1974, 1975a, b, 1976; Cochrane *et al.,* 1976.)

The satellites, Landsat-I* and Landsat-II, operate on a sun-synchronous, near-polar orbit at an altitude of 915 km, providing an 18-day repeat cycle for areas. Orbits have been adjusted so that areas covered by direct transmission to ground receiving stations from both satellites receive information at a 6-day followed by a 12-day interval. For New Zealand there is an 18-day repeat cycle from Landsat-II — weather and priorities permitting — with information stored on a tape-recorder. These data are subsequently transmitted to ground receiving stations in North America during night-time passes. Consequently, there is

*Landsat I was switched off in January 1978. Landsat III was launched in March 1978. These two satellites provide a nine-day repeat cycle for areas.

a time delay currently for the receipt of data. Thus, if New Zealand had its own ground receiving station it could receive real time data with obvious advantages of this for monitoring pasture conditions and broad management policies. This applies also to many other uses of Landsat data.

FORMAT OF LANDSAT DATA

The Landsat MSS records radiances of objects in four separate spectral bands ranging from 0.5 to 1.1 μm. Bands 4, 5, 6 and 7, respectively, record wavelengths of 0.5 to 0.6, 0.6 to 0.7, 0.7 to 0.8 and 0.8 to 1.1 μm. These are available as magnetic tapes (computer compatible tapes — CCTs) or reconstituted as separate band black and white 70 mm or 220 mm photographic products. The most usual form available is as 1: 1 000 000 black and white prints of single bands. These conform to the United States Geological Survey (USGS) national standards of accuracy for mapping (Colvocoresses, 1974). Any two or more separate band photographs can be reproduced as a colour composite through the use of special filters to provide colour-enhanced imagery. A common combination is to use bands 4, 5 and 7 to give a simulated colour-infrared-colour composite image. Other band combinations using 'only positive transparencies, only negative transparencies, or mixtures of both can be used for special purposes.

A greatly increased range of data can be extracted from Landsat multiband imagery by these optical colour enhancement processes than is possible from analysis of single black and white band photographs. For example, differences between tussock and exotic grasses, between highly productive and less productive pastures, and between pastures and field crops are more readily detected.

"Quick Look" black and white 70 mm positive prints showing e&h of the four bands printed on one 240 x 190 mm sheet are available for all New Zealand Landsat scenes from the Lands and Survey Photographic Library in Wellington. Imagery of Landsat scenes anywhere in the world are available from the EROS Data Center in Sioux Falls, South Dakota 57198, U.S.A., for a nominal sum.

Digitally enhanced photographic products in both black and white and colour can also be obtained from EROS Data Center or from processing with a range of sophisticated machines such as IBM, General Electric's "GE100", and Optronic's "Photo write". All of these produce imagery with superior definition,

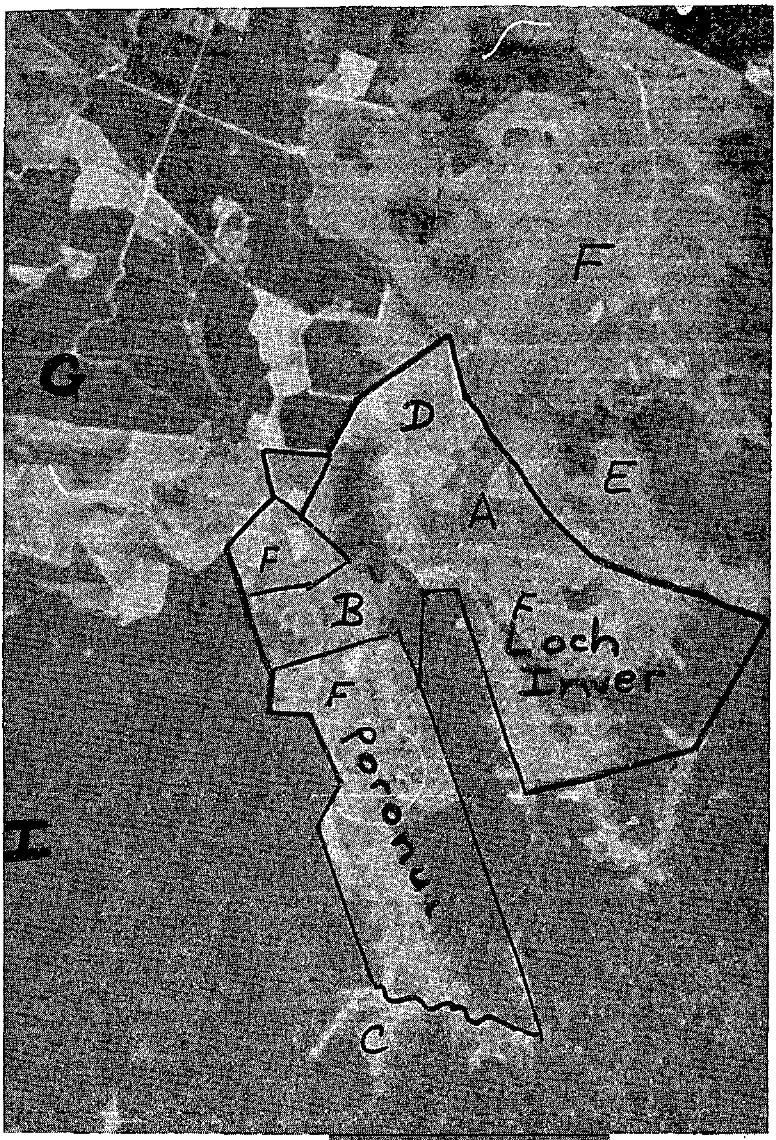

FIG. *2: Part of Landsat MSS band 4 image of eastern Taupo, Waimihia and Kaingaroa Forests, Kaimanawa Range, Lochinver and Poronui stations.*

A, large fields of lucerne and new pasture; B, area of fern and scrub; C, area of tussock; D, area prepared for new planting; E, area of fern and scrub; F, areas of exotic pastures with some lucerne; G, exotic forest plantations of *Pinus ponderosp, P. radiata, P. nigra,* and *Pseudotsuga menziesii;* H, indigenous scrub (manuka dominant); and I, predominantly *Nothofagus* forest of Kaimanawa Range.

enhanced contrast and reduction of "noise". Figure 2 is an example of part of a conventional Landsat MSS band 4 photograph of an area north and east of Lake Taupo. Boundaries of Poronui and Lochinver stations are superimposed as well as letters for reference to specific classes of land cover. Figure 3

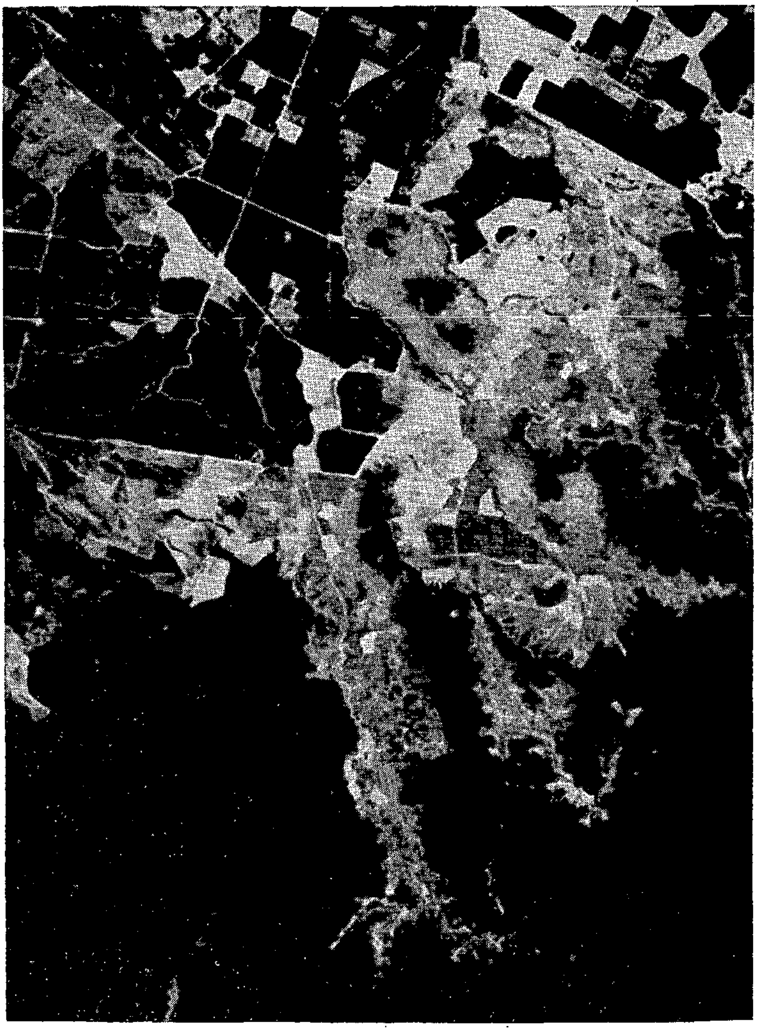

FIG. 3: *Copy of Photowrite digitally enhanced Landsat MSS band 4 image of the same area as Fig. 2 at slightly smaller scale. Note the sharper resolution, more defail present and greater range of grey scale tones, especially in areas F of Fig. 2.*

is a copy of part of a digitally enhanced Band 4 photograph produced by Optronic's Photowrite in U.S.A. There is a possibility that a central Photowrite facility may be available for New Zealand users at DSIR PEL Remote Sensing unit in 1978.

Despite the fact that there has been substantial degradation of resolution in the printing process, comparison of Figs. 2 and 3 clearly demonstrates the superior qualities of the enhanced image (Fig. 3) for photographic analysis. The original photographs show much more striking contrast than is depicted in Figs'. 2 and 3. Differentiation on a field-by-field basis is possible on Fig. 3; only broad categories are recognizable on comparable areas in Fig. 2.

METHODS OF ANALYSIS

Landsat data provide large-area synoptic view's portraying geologic, ecologic, and landcover patterns that have been obtained under uniform height, lighting. and angle of view conditions for any one image. Tonal contrasts (i.e., spectral reflectances), therefore, represent real differences not differences due to variations in 'light, time, season, angle of view, film processing and photographic printing that are inherent in aerial photographs or photo mosaics of large areas. The large area coverage and relatively frequent repetitive or sequential survey facilitate recognition of zones of importance and also temporal patterns of change. This "highlighting" of areas of interest provides important economies of time for broad-scale surveys and for monitoring progress or change. It also serves as a useful base for regional or national planning..

Some critics condemn Landsat 1: 1 000 000 imagery as too broad, 'coarse and generalized, unaware that there are analytical procedures enabling surveys at increasingly larger scales to be carried out with increased information and detail to be gained. Figure 4, showing 27 categories of land-use or land cover for the, Aupouri Peninsula, was mapped from simple enlargement of Landsat photographs (E-1648-21420 and E-2391-21273). The areas on the original 1 : 1 000 000 prints measured only 80 mm x 20 mm. Further breakdown of some of these classes is possible with other analytical techniques.

Landsat data can be used at different scales for a wide range of applied applications including pasture surveys (Carneggie et ***al.,*** 1974; Poulton ef *al.,* 1975; Myers et *al.,* 1975) employing any one or combinations of the four techniques photographic, optical, electronic, and digital. Estes et al. (1975) and Lintz and Simonett (1976) provide valuable surveys of the fundamentals of image interpretation with many applied examples that embrace the first three techniques. Hajic and Simonett (1976) outline a useful range of procedures for digital processing of Landsat data.

Carneggie et *al.* (1974) used Landsat 1: 1 000 000 colour composites to monitor the beginnings of annual pasture growth, its progressive increase in vigour and productivity to maturity, and sequential drying off or dying for the whole of the southern two-thirds of the State of California. These studies were equated with regular ground photographs of a series of representative test

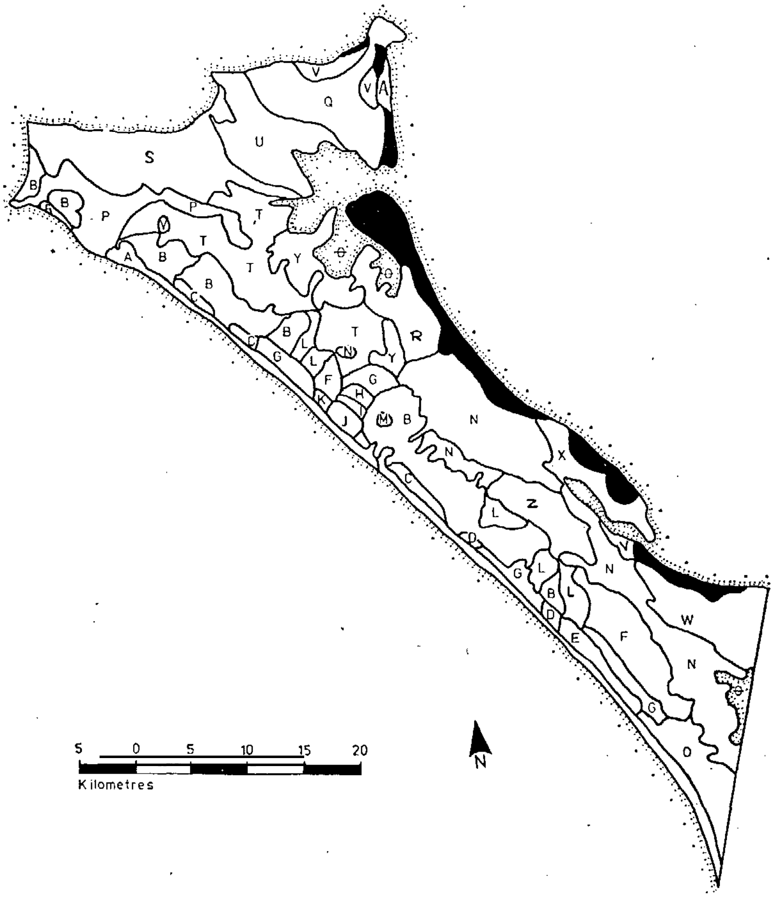

FIG. 4: *Land-use map of Aupouri Peninsula derived from Landsat imagery.*

sites throughout the state at the same time as the satellite overpass. Radiance measurements and biomass productivity from clip quadrat sampling were also carried out corresponding to times of Landsat orbits. Thus,, the sequential phenology maps, at 18-day intervals, of annual pasture growth for California, based on qualitative tonal contrasts recorded on the Landsat colour composites, could be exactly evaluated against precise radiance values and biomass measurements of productivity. The practical utility of such information on a state-wide basis requires no stressing. Many other studies mapping the phenology of pastures or other

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Notes to Fig. 4 (opposite)

LAND-USE/LAND COVER CLASSES, AUPOURI PENINSULA

Categories	*Symbol*
East Coast Parengarenga sand	Black
West coast sand: relatively unstable dunes:	
Intertidal and salt flats	A
Unvegetated sanddunes, shifting sand	B
Foredunes with marram grass	C
Foredunes with *Scirpus* sedge	D
Foredunes with flax	E
Dunes with lupins	F
Dunes with pines, undifferentiated age	G
Dunes with pines, planted 1971	H
Dunes with pines, planted 1973	I
Dunes with pines, planted 1972	J
Dunes with pines, planted 1974	K
More stable dunes:	
Marram association	L
Coastal forest	M
Established pasture	N
Established pine	0
Non-sand areas:	
Developed pasture on chiefly volcanic soils	P
Developed pasture on other soils	Y
Scrubland:	
North Cape type	Q
Parengarenga type	R
West coast highland type	S
West coast lowland type	T
Gumland type	U
Mt Camel type	X
Ngataki type	Z
Mangrove associations	0
Freshwater swamp:	
Manuka-swamp associations	V
Wiwi-raupo associations	W

species have followed. The terms "green wave" for initiation of growth, and "brown wave" for decline, drying off or dying have become accepted terms when mapping from Landsat imagery.

Such pattterns of seasonal productivity have similar parallels in much of New Zealand. Sequential imagery of Canterbury, Marlborough, Wairarapa and Otago, although not available as regularly as in the Californian study, provide examples for the potential adoption of such methods of pasture survey. Preliminary sequential surveys on a qualitative basis have been initiated by the writer for Marlborough-Wairarapa and for Otago.

PHOTOGRAPHIC TECHNIQUES

Standard photo interpretatiori techniques using Landsat black and white single band imagery and colour composites at 1: 1 000 000 scale and enlargements up to 1: 100 000 provide useful practical working maps. Tonal contrast is the major differentiating criterion for small-scale imagery. As spectral signatures of pastures commonly vary with different wavelengths, use is made of this by comparing photographic tones on different Landsat bands. The added diniensions thus provided enable an interpreter to analyse patterns with a greater surety than is possible even on much larger scale conventional aerial photography.

Preliminary studies of single band Landsat images of Southland, Otago, Canterbury, Westland, Marlborough, Wairarapa. Manawatu, Volcanic Plateau, East Coast, South Auckland, and Northland peninsula show conclusively that they provide a range of information about pastures that is difficult or in some cases impossible to obtain from conventional aerial photography.

Comparison of Landsat-II scenes, E-2282-2 1525, E-2299-2 1190 and E-2335-21 183 of October 3 1, November 17, and December 23, 1975, respectively, demonstrates changes in seasonal vigour of pastures in the Wairarapa and Marlborough areas. These changing patterns are recognizable from inspection of single-band imagery, but are much more readily obvious when using colour composites. Seasonal changes in Canterbury pastures are also clearly seen from inspection of Landsat imagery of winter (E-2192-05311, E-2192-21272)) spring (E-2265-21321 1, E-2282-21252), and summer (E-1502-21362, E-2355-21190 and E-2390-21240). Seasonal pasture change and variations in pasture quality and composition are also well illustrated in Landsat imagery of Otago (E-1503-21421, E-2787-21 172, E-2805-21 163, and E-2805-21 165). Seasonal coverage with Landsat imagery is not as good as the above areas for other parts of New Zealand but there is imagery for most of the country.

Multispectral analysis of E-2787-21 172 of Landsat MSS bands 4, 5, 6 and 7 photographic images of North Otago and the Mackenzie Basin of March 19, 1977, and image scene E-2805 21163 eighteen days later (April 6, 1977) are excellent examples of the use of satellite remote sensing for pasture analysis. Comparison of these images shows pasture variations resulting from differences in soils, in pasture composition, and farm management that are not possible to recognize even from large-scale aerial photographs. Additionally, because Landsat imagery is acquired under uniform light and angle of view conditions for a large area at the same time, for comparative purposes Landsat data are greatly superior to aerial photography where tonal contrasts may arise from a great many factors — differences in time, light, angle of view, altitude, etc. — rather than from inherent differences in the pastures at one time.

Differences. in spectral reflectances of pastures recorded on each of bands 4, 5, 6 and 7 reflect variations in sward density, and particularly vigour of plants and soil moisture availability. These can be seen clearly on Landsat E-2334-21 123 of December 23, 1975 for the areas south of Lake Rotorua, the Galatea Basin and much of Hawke's Bay and East Coast.

TABLE 1: USEFULNESS OF BANDS 4, 5 AND 6 FOR DISTINGUISHING PASTURE LAND COVER AT SMALL SCALES

Categories	*Bands* 4	5	6
Exotic pasture from:			
tussock	poor	poor	very good
crushed scrub	poor	moderate	very good
scrub	poor	moderate	very good
swede crop	very good	very good	poor
lucerne	poor	moderate	moderate

Table 1 summarizes some of the differences between Landsat MSS bands found useful in multiband analysis for differentiating pastures and agricultural crops in the Taupo area. Comparison of Figs. 2, 3, 5 and 6, showing the Poronui and Lochinver stations east of Lake Taupo, illustrate that each band can contribute information that collectively facilitates pasture mapping.

Figures 5 and 6, showing Photowrite bands 5 and 6, respectively, should be compared with the band 4 images (Figs. 2 and

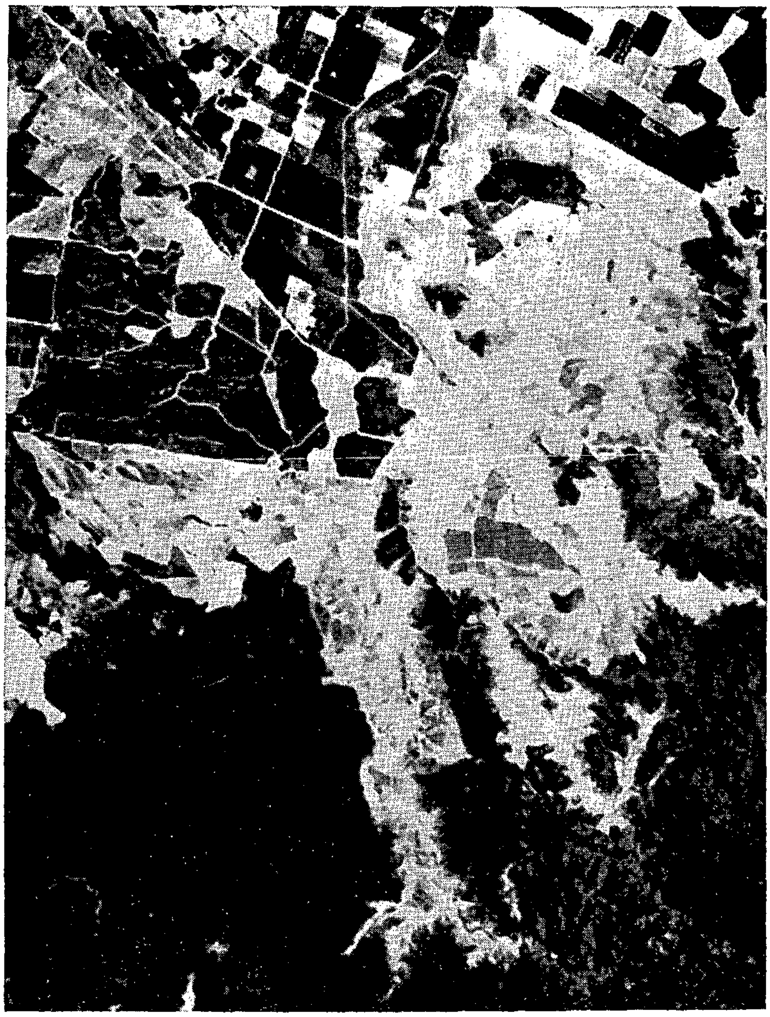

FIG. 5: Copy *of* ***Photowrite digitally enhanced*** *Landsat* ***MSS band*** *5* ***image*** (*E-2334-21123*) ***of the east Taupo area (Fig. 2) at*** *slightly smaller scale.*

Note the better definition of exotic forest species within the Waimihia State Forest. Cleared areas and newly harvested lucerne have lighter tones than in the band 4 images.

FIG. 6: *Copy of Photowrite digially enhanced Landsat MSS band 6 image (E-2334-21123) of the east Taupo region.*

Note the clear recognition of exotic pastures (F) from fern and scrub (B and E) and tussock grassland (C) and lucerne fields (A) and the very detailed field boundaries in the northern part (F and to the north) of Poronui station. Used in comparison with Figs. 5 and 3, a detailed pattern can be recognized that can be subsequently analysed from ground sampling.

3) noting the very different boundaries that appear. Category F (sown exotic pastures) is most clearly separated from adjacent areas of tussock, fern, scrub and cleared areas on the near infra-red bands 6 or 7. Used in conjunction with band 5, which clearly shows the pasture-scrub interface, area C (tussock grass) can be readily mapped.

Areas B and E, of fern, scrub and some tussock, cannot be separated from pastures, lucerne or cleared areas on bands 4 and 5 (Figs. 2, 3 and 5). The boundaries are strong and clearly separate this entity from pastures and lucerne on band 6 (Fig. 6).

Great economies of time and expense can be achieved for mapping and planning purposes as selected representative areas recorded on Landsat images can be compared with aircraft photographs and final checking made at ground. sites. Where similar signatures are present these can normally be assumed to represent similar conditions to those verified in the second and third tier sampling.

Only at sufficiently large scales when the added photo interpretation properties of texture, size and shape are present on aerial photographs do conventional aerial photos provide an equal or more accurate assessment than the tonal contrasts present on Landsat multispectral images. For narrow band spectral radiance differences, however, conventional aerial photography cannot provide some information. Although this can be obtained by aircraft using multispectral cameras, the problems of variable time, light, angle of view, etc., are still present, so less confidence can be attributed to tonal differences than with the smaller scale Landsat imagery.

High quality colour composites — particularly if enlarged photographically as a print or optically by projection of a positive transparency — have the added merit of colour hues to help differentiate tonal differences.

Figure 7, a panchromatic copy of a colour composite of Lochinver-Poronui stations, loses much of the subtle colour hues in reproduction, but nevertheless demonstrates greater information than any individual black and white band.

Ability to differentiate classes increases with larger scales. These categories and many others become easily distinguishable on simulated colour-infrared-colour composites. Thus. exotic pasture on soils derived from Tarawera lapilli and Rotomahana mud in the area south of Lake Rerewhakaitu appear the same in the field and from conventional photography including colour aerial photography. They are readily differentiated on colour com-

FIG. 7: *Black and white copy of a simulated colour infrared colour composite (2334-21123) of Poronui-Lochinver-Waimihia State Forest-Kaimanawa area.*

Although much of the subtle colour tone details are lost in this black and white reproduction, most of the boundaries recognized separately on bands 4, 5 and 6 (Figs. 3, 5 and 6) are present on, this single photograph. Comparison of this photograph with the categories A to I inclusive shown on Fig. 2, and these same areas on Figs. 3, 5 and 6, shows that there is a greater amount of detail present on Fig. 7 than on any other individual black and white band image.

posites because of the different narrow band spectral signatures from the pastures. Similarly, pastures on Taupo ash and on alluvial soils in the Galatea Basin can be readily mapped from Landsat colour composites. Pastures growing on old brown sands and on younger white sands in the Aupouri peninsula can be recognized on colour composite images even at scales of 1: 1 000 000. This cannot be achieved even with large-scale panchromatic aerial photographs.

OPTICAL PROCESSING

By the use of colour additive viewers, spectral constrasts on different multiband transparencies can be colour enhanced to provide additional interpretive information. Different filters, a range of light intensities, and varying combinations of both positive and/or negative transparencies provide a wide varitey of processing alternatives. Some New Zealand applications have been illustrated in the DSIR PEL *Quarterly Reports on LANDSAT Applications* of 1976 and 1977.

ELECTRONIC PROCESSING

A colour isodensitometer provides density slicing, colour enhancement and variable magnification, all of which can greatly increase the range of information extractable from Landsat transparencies. Isodensitometer machines register areas of equal density on Landsat transparencies. This electronic density slicing provides many more categories than can be recognized in normal photo interpretation or with optical processing by additive viewers. Additionally, most isodensitometers register each of the densities with a different colour, which greatly facilitates recognition of patterns. Inherent in all density slicing procedures is a loss of sharp detail but there is an increase in another form of information because of the clearer distinction possible with the colour patterns portraying areas of similar film grey scale densities. Large areas can be rapidly scanned or a selected smaller area can be enlarged to scales ten times greater than is possible with photographic enlargement. Examples of these sorts of applications are shown in the American Society of Photogrammetry's *Manual of Remote Sensing* (Janza, 1975; Bowden, 1975). Frequently, such density variations cannot be recognized by the unaided human eye.

DIGITAL PROCESSING: LANDSAT COMPUTER COMPATIBLE TAPES

The CCTs have certain advantages over photographic products and can provide an additional range of information to a larger scale than with photographs.

Computer compatible tapes are a first generation product with pixel (picture element) resolution not degraded by multiple copying as is the case with photographs. Thus, small differences in radiances of targets can be distinguised on CCTs but not on photographic products. Thematic mapping by cluster analysis enables desired categories — exotic pasture, tussock, stressed pasture, scrub,, forest, etc. — to be mapped automatically by computer. As each pixel represents the scene radiance from a surface area of 79 x 59 metres, considerable detail can be extracted at quite large scales (see DSIR PEL *Quarferly Reporfs* of 1976, 1977 for various examples of these techniques). A comparative analysis of all these methods — applied to mapping suspended sediments — that can, however, be applied to any analysis recording differences in radiance values of features — e.g., pastures — is given by Cochrane and Male, 1977; Cochrane and Hajic, 1978).

Again economics in mapping can be achieved by using a three-tiered sampling method. Selected representative areas recognized on the computer maps can be compared with recent aerial photographs and ground sampling carried out within the photo sample area for verification or establishing quantitative data.

FUTURE APPLICATIONS

Receipt of Landsat I and II data of New Zealand has been sporadic. With the launching in March 1978 of Landsat-C it is hoped that data acquisition will be more regular. In addition to the four band MSS used on Landsat I and II, Landsat-C has a fifth sensor band monitoring emissive radiation in the 10.4 to 12.6 μm wavelength band. Capability for daytime and night-time monitoring of thermal differences but at coarser resolution (240 m) should prove useful in pasture analysis. It is also planned to provide photographic coverage at a scale of 1: 500 000 with resolution to 40 metres to augment the standard MSS imagery. Such resolution closely approximates the threshold for detailed discrimination of features, giving details equivalent to those obtainable from medium altitude photgraphy. Thus, the utility of Landsat data for pasture analysis promises to improve. For many areas a substantial decrease in dependence upon the second tier of sampling — aircraft photography — is likely. Refinement of analytical procedures, coupled with improved collection of ground data, offer promising prospects for remote sensing applications in pasture analysis.

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