LANDSAT II DIGITAL DATA ANALYSIS AND MT TARAWERA VEGETATION

SUSAN M. TIMMINS

Biological Sciences Department, University of Waikato, Hamilton, New Zealand[1]

SUMMARY: Digital data collected by Landsat II satellite were used to produce a vegetation map of Mt Tarawera, Rotorua, New Zealand. The accuracy of this map, when checked in the field, varied for each class of vegetation; low stature and cover vegetation were more reliably classified than tall forest. The average probability of a resolution unit being correctly classified (with 95% confidence limits) was 65% when strict vegetation class definitions were used, and 88 % when more flexible definitions were adopted.

INTRODUCTION

Most New Zealand studies to have used data from Landsat satellites to map vegetation cover have been concerned with land use or agricultural mapping (Batty, 1977; Child and Dickson, 1978; Cochrane and Batty, 1978; Hicks, 1978; Moody, 1979; Thomas *et al.,* 1978; Thomas, Benning and Bennetts, 1980). Dale (1978) and Strachan (1977) mapped the native vegetation of King Country and East Taupo respectively but using predominantly Landsat II colour products.

This paper reports an attempt to derive a botanically useful classification and map of native vegetation on a small area using Landsat digital data. The study area was Mt Tarawera, a group of rhyolitic domes, which erupted in 1886, located 24 km east of Rotorua, North Island, New Zealand.

LANDSAT DATA COLLECTION AND CHARACTERISTICS

The underlying principle of Landsat data analysis is that all objects on the earth's surface reflect incident radiation in a characteristic manner (Landgrebe, 1976). Different vegetation types have different reflectance characteristics because of variation in species present, their density, the soil and moisture regime of the area, and many other biophysical factors. Landsat data analysis discriminates between different land cover types by exploiting these differences in 'spectral signatures'.

Landsat H carries a multispectral scanning system which records the intensity of electromagnetic radiation reflected from the earth in four discrete wavelength ranges (Hewish, 1980):

band 4	0.5 - 0.6 um	(green)
band 5	0.6 - 0.7 um	(yellow-red)
band 6	0.7 - 0.8 um	(red and near infrared)
band 7	0.8 – 1.l um	(near infrared)

The instantaneous field of view (IFOV) of each sensor of the multispectral scanning system (MSS) is a square c. 79 x 79 m. However, the IFOVs are sampled at a rate such that the MSS radiance values correspond to areas on the ground of 56 x 79 m (USGS, 1979). Ultimately, a set of four numbers, representing the intensities in each of the four bands, for each 56 x 79 m areas (pixel) is recorded on computer compatible tape (CCT). The data are then available for Landsat digital data analysis.

METHOD

Outline

The method of Landsat digital data analysis used in this study was a 'supervised, parallelepiped' type (Swain, 1978). The essential procedures were 'training', 'theming' and 'testing' (Fig. 1).

Areas of known vegetation type were selected as 'training sites' (area 1, Fig. 1) to represent the range of vegetation types and topography on Mt Tarawera. They were homogeneous with respect to vegetation, slope and aspect, and accessible. The vegetation and conditions at these sites were surveyed using the method of Druce (1959) and the sites were classified according to the naming scheme devised by Atkinson (1962).

For each vegetation type, the range of radiance intensities reflected in each wavelength band was determined from the Landsat digital data. This became the 'spectral signature' or assay for that particular vegetation type. A computer was 'trained' to recognise and search the Landsat data for the spectral pattern characteristic of each vegetation type. Pixels satisfying the spectral criteria of a class were assigned a symbol peculiar to that class, for production of a final map by lineprinter. Colour prints of the final

[1]. Present address: Remote Sensing Section, Physics and Engineering Laboratory, DSIR, Private Bag, Lower Hutt, New Zealand.

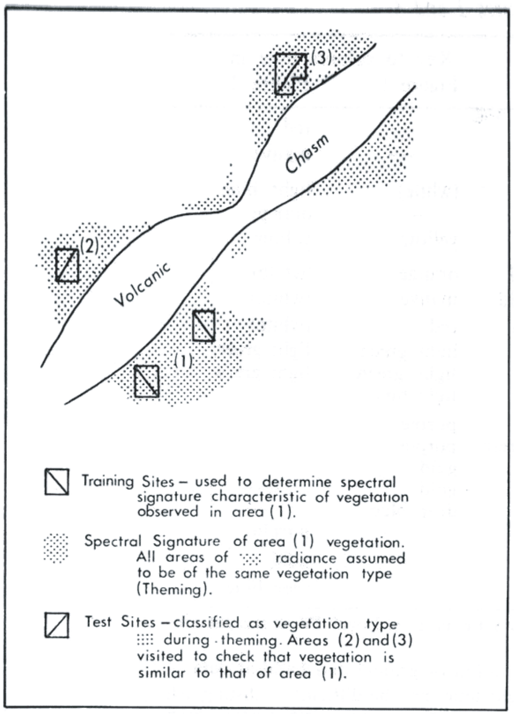

FIGURE 1. *Important stages of Landsat data analysis spectral signature definition, training, theming and testing.*

map were also produced on the Optronics Colorwrite machine, at Remote Sensing Section, Physics and Engineering Laboratory (PEL), DSIR, Wellington.

Once the final Landsat vegetation map had been produced, its accuracy was determined. Representative areas on Mt Tarawera were checked to establish if the mapped vegetation type matched that on the ground (areas 2 and 3, Fig. 1). The results were recorded as the number of pixels correctly classified.

The computer packages DOGMA (used on a PDP 11/70 at University of Waikato) and LANSYS I (on an IBM 30/33, used at Remote Sensing Section, PEL) were employed to process the digital data to achieve 'training', 'theming' and 'testing'.

Location of training sites

To extract the spectral signature associated with a vegetation type from the Landsat data, it was necessary to locate the training sites for each vegetation type in the Landsat data lineprinter output. All subsequent procedures in Landsat data analysis depend on the precision of this registration procedure which proved to be the most difficult task of the study.

Several methods of registration were attempted, all of which failed due to geometric distortions inherent in Landsat digital data and Colorwrite and lineprinter writing distortions. The Landsat digital data for a whole scene typically have geometric distortions equivalent to about 300 m on the ground (McDonnell, 1978). A digital image rectification package has now been developed at Remote Sensing Section, PEL, DSIR, using ground control points to calculate a cartographic correction factor (McDonnell, 1978), but it was unavailable at the time of this study.

The problem of mismatch between Landsat and ground data was overcome using two types of Landsat products to locate training sites (Benning and Thomas, pers. comm.). A grey map, in which each alphanumeric character symbolised two CCT levels, was prepared in each wavelength band.

Two hue and texturally-enhanced Colorwrite images of the study area, at an approximate scale of 1 : 78000, were also produced (McDonnell, 1979; Thomas, 1979). The textural enhancement sharpened the boundaries between unlike pixels, making the individual pixels visible to the naked eye. The hue enhancement brought out forest detail on one image and herbfield/scoria cover on the other.

Pixels which could be located accurately both on the Colorwrite product and the grey maps, such as promontories along the lake edges, were used as location control points. Training sites were located on the Colorwrite product visually by interpretation of tone, colour, shape and proximity to recognisable geographic features. The same position was found on the lineprinter output by counting pixels horizontally and vertically from one of the control points to the training site. The radiance values in each wavelength band for each training site were then read off the grey map.

Assessing map accuracy

Testing procedures followed Thomas *et al.* (1980), after Landgrebe (1973). For each vegetation class, a number of test areas (usually five pixels square) were selected throughout the study region on varying slopes and aspect, and in different positions from the-training sites (areas 2 and 3, Fig 1). Field testing was conducted at both level II and level III (after Anderson *et al.,* 1972) to check if the pixels in each of the test areas were correctly classified. The Landsat data were collected in 1975 and, therefore, the map had to be appropriate for the 1975 vegetation condition.

TABLE 1. *Vegetation classes represented in Figures* 2 *and* 3.

Class name			Key to colours used in	
Level 1	Level II	Training[b]	Figure 2	Figure 3
		Bare	—	red
		Dome Edge	—	mauve
		Mossland	(white)	light blue
		Tutu and Scoria	—	orange
		Herbfield	yellow	yellow
		Shrubs/Herbfield	orange	(white)
		Kanuka/Herbfield	mauve[c]	(white)
		Kanuka-Manuka red		(white)
		Mixed Shrubs	light green	light green
		Shrubs Sun	light green	light green
		Tall Manuka	light blue	—
Forest	Hardwood F	Native Forest	purple	—
		Low Reflect Forest	purple	—
		Bright Forest	gold	—
		Sunny Forest	gold	—
		Dull Forest	deep blue	—
	Softwood F	Exotic Pine	—	purple
Agriculture	Pasture	Pasture	—	gold
Water	Lake	Water		deep blue

a After Anderson *et al*. (1972). Progression from Level I to Level IV represents increasing subdivision of groups.

b The final classes used successfully in the calibration of ground and Landsat data.

c The colours red and mauve, deep blue and light blue may be difficult to distinguish on the map. The large scree slope, between the northern and north-western lava flows, is predominantly red with scattered mauve pixels in Figure 2. Only the lake is deep blue in Figure 3.

In areas where changes had probably occurred, the likely 1975 vegetation was interpolated from photographs. the 1980 field condition. and a knowledge of the approximate growth rates of the relevant plants.

The results were tabulated as the probability that an area classified as a particular cover type was correctly classified, with 95 % confidence limits. An average figure of accuracy -for the whole map was also calculated.

Flaws were recognised in the above testing method. No allowance was made for classifications that were nearly right, nor for isolated pixels, the latter suffered edge effects and were more likely to be transitional stands. There was also a tendency to select homogeneous test sites even though homegeneity was not typical of the study area.

Implicit in the testing method was the false assumption that the exact 56 x 79 m area on the ground to which each test pixel value related, could be located. The problem was partially alleviated by selecting a small block of pixels within a larger block of the same vegetation. However, it was difficult to find large groups of pixels for some classes and the accuracy figures were still given in terms of individual pixels.

The arbitrary boundaries of the original classes ultimately make it difficult to support a purely objective testing method. The method implied the ability to decide categorically to which cover type a site should belong. This notion is, of course. indefensible (Curtis, 1959).

RESULTS

The vegetation map and vegetation descriptions

Figures 2 and 3 constitute the final vegetation map of Mt Tarawera. Only nine colours can be reliably distinguished on a single Colorwrite print and thus the two prints accommodate the 15 classes of the final vegetation map.

A key to the colours used in the map(s) is given in Table I and the 'level' of the mapping indicated. The training classes used to produce the final map of Mt Tarawera are described below; species names follow Druce and Ogle (1972).

1. *Bare*. Boulders, ash and lapilli dominate. The 10% plant cover is contributed by many herbs, *Muehlenbeckia axillaris* and *Raoulia albosericea,* grasses, lichens and mosses.
2. *Dome Edge*. This is a topographic rather than vegetation class, being steep, often with bare rocky cliffs, and usually on the western faces of the domes.
3. *Mossland*. A 7;90; in which *Racomitrium lanuginosum* var. *pruinosum* contributes up to 70% of the canopy cover. Other species present include monoao *(Dracophyllum subulatum), Gaultheria oppositifolia, Raoulia albosericea. R. glabra. Polytrichum* sp., *Rytidosperma viride,* and *Celmisia gracilenta* var. Most of the cover is less than 10 cm high and bare scoria is significant in most zones.
4. *Tutu and Scoria*. A type intermediate in cover and species composition between 'Bare' and the following 'Herbfield' type in which tutu *(Coriaria arborea* var. *arborea)* is rapidly invading the bare scoria. 'Tutu and Scoria' has a higher percentage of scoria (35%) than 'Herbfield' and a lower percentage of *Racomitrium* (5%) than 'Mossland'.
5. *Herbfield*. A low herbfield with sparsely scattered shrubs 1.2 - 4 m tall and about 25-30% scoria. The herbfield is composed of lichens *(Cladia retipora, Cladonia leptoclada)* and mosses *(Campy lop us clavatus);* herbs *(Raoulia albosericea, R. glabra);* shrub species filling a herb niche *(Pimelea prostrata* var. *prostrata. Gaultheria paniculata. G. oppositifolia. Erica lusitanica),* and the sedge *Morelotia affinis* and grass *Rytidosperma viride*. Tutu and monoao are important taller shrubs contributing 35 % of the canopy.
6. *Shrubs / Herbfield*. Half the vegetation cover is contributed by shrubs, tutu (1 - 2.5 m), manuka (*Leptospermum scoparium*) (0.5 - 1.8 m) and prickly mingimingi *(Leucopogon fasciculatus)* (0.3 - 1.0 m); and half by herbfield species, as in 5. Scoria contributes 20-25% of the canopy. 'Shrubs/Herbfield' has greater cover, and more tall shrubs than 'Herbfield'.
7. *Kanuka/Herbfield*. A kanuka *(Leptospermum ericoides* Var. *ericoides)* scrub in which half the canopy is a low 1.2 - 2.4 m scrub of predominantly kanuka plus manuka, lupin *(Lupinus arboreus), Gaultheria oppositifolia. G. antipoda*. mingimingi *(Cyathodes juniperina), Olearia furfuracea,* koromiko *(Hebe stricta* var. *stricta)*. and *Pomaderris ericifolia*. Very low herbfield species, as in 5 contribute the remainder of the canopy cover. Scoria contributes 15% of the 'canopy'.
8. *Kanuka-Manuka*. A kanuka and manuka treeland 4.5 – 7.0m high with the occasional broadleaf *(Griselinia littoralis)* or rewarewa *(Knightia excelsa)* but particularly with small. distinct pockets of law kanuka scrub (7.) amongst it. The kanuka and manuka overtop a distinct second layer of the two mingimingis, *Olearia furfuracea* and *Gaultheria antipoda*. Total cover is 80-90 % but top layer cover is only 40%.

9a. *Mixed Shrubs*. A mixture of hardwood shrubs 1 - 6 m high dominates. It has an even cover of rounded crowned, predominantly broadleafed species; a total cover of 100% and top layer cover of 50 %. Kohuhu *(Pittosporum tenuifolium* var. *tenuifolium), Olearia furfuracea* and kamahi *(Weinmannia racemosa* var. *racemosa)* are consistently important shrubs. Tutu, karamu *(Coprosma robusta),* five finger *(Pseudopanax arboreus* var. *arboreus),* koromiko, heketara *(Olearia rani)* and manuka are often present.

9b. *Shrubs Sun*. A scrub of mixed hardwoods as above (9a.) in high incident light conditions at the time of Landsat data collection i.e. on east facing valley sides. As a result the radiance values of this class were higher than those for 'Mixed Shrubs' and a separate training class was required. 'Mixed Shrubs' and 'Shrubs Sun. are combined in the final map (Figs. 2 and 3).

10. *Tall Manuka*. The dominant canopy species is manuka 4.5 - 6.0 m tall and comprising 50-60% of the canopy cover. Kamahi (4.5 - 6.0 m) may also be an important emergent canopy species. In the valley sides north of the volcanic chasm, kohuhu is important. Manuka occurs in all strata. Other hardwood shrubs, tutu. koromiko, *Olearia furfuracea*. *Coprosma tenuifolia*. karamu and five finger are all 1.5-2.0 m tall. Total cover is about 95 %.

11a. *Native Forest*. Extending up to an altitude of about 600 m on the north-west slopes and to 850 m on the south-east slopes of Mt Tarawera. The dominant species is kamahi, which occurs both in almost pure pole stands, and in association with other hardwoods, particularly rewarewa and tawa *(Beilschmiedia tawa),* as well as with kohuhu, broadleaf, toatoa *(Phyllocladus glaucus),* Hall's totara *(Podocarpus*

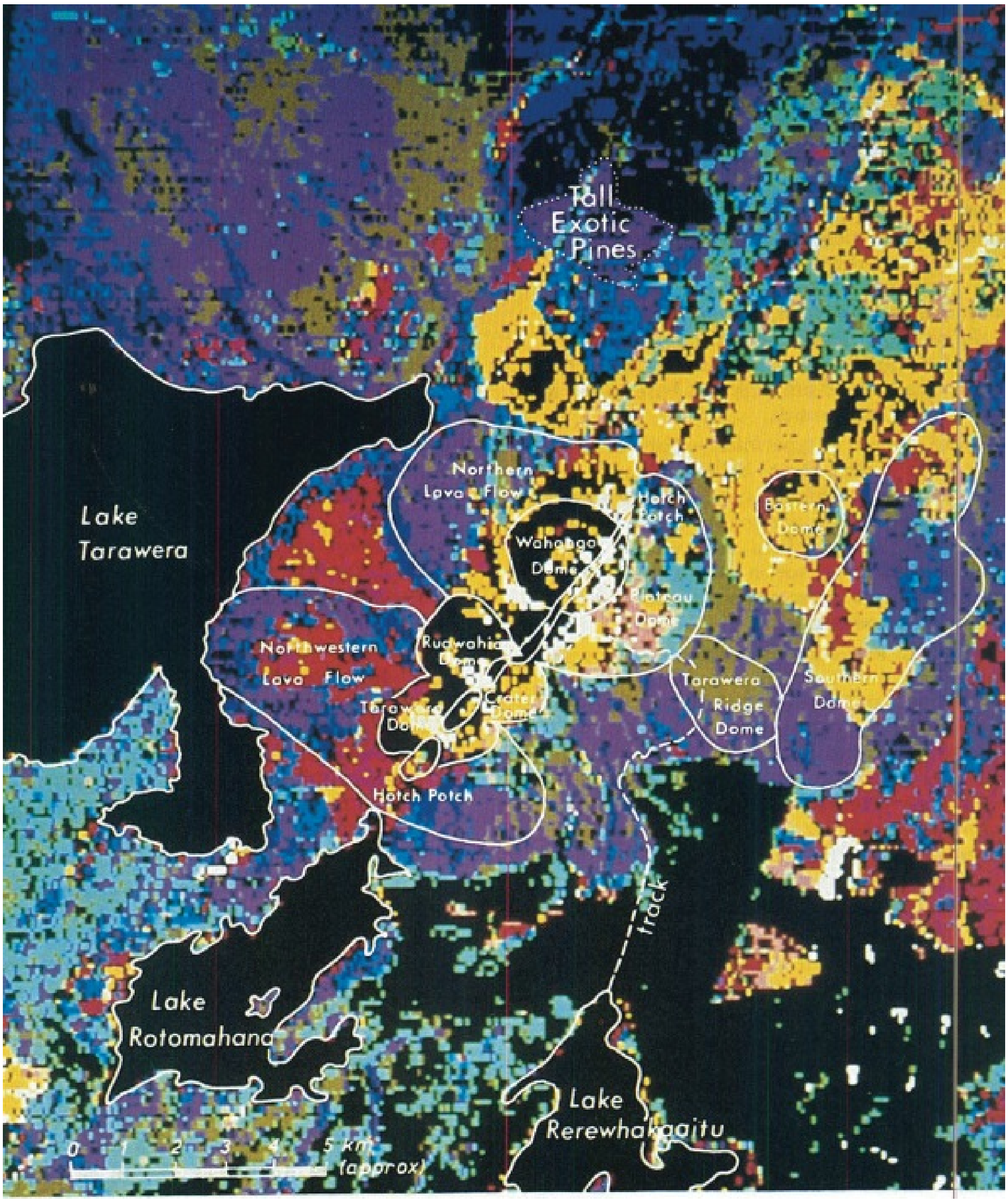

FIGURE 2. *Final map of the Mt Tarawera vegetation, derived from Landsat digital data analysis (A).*

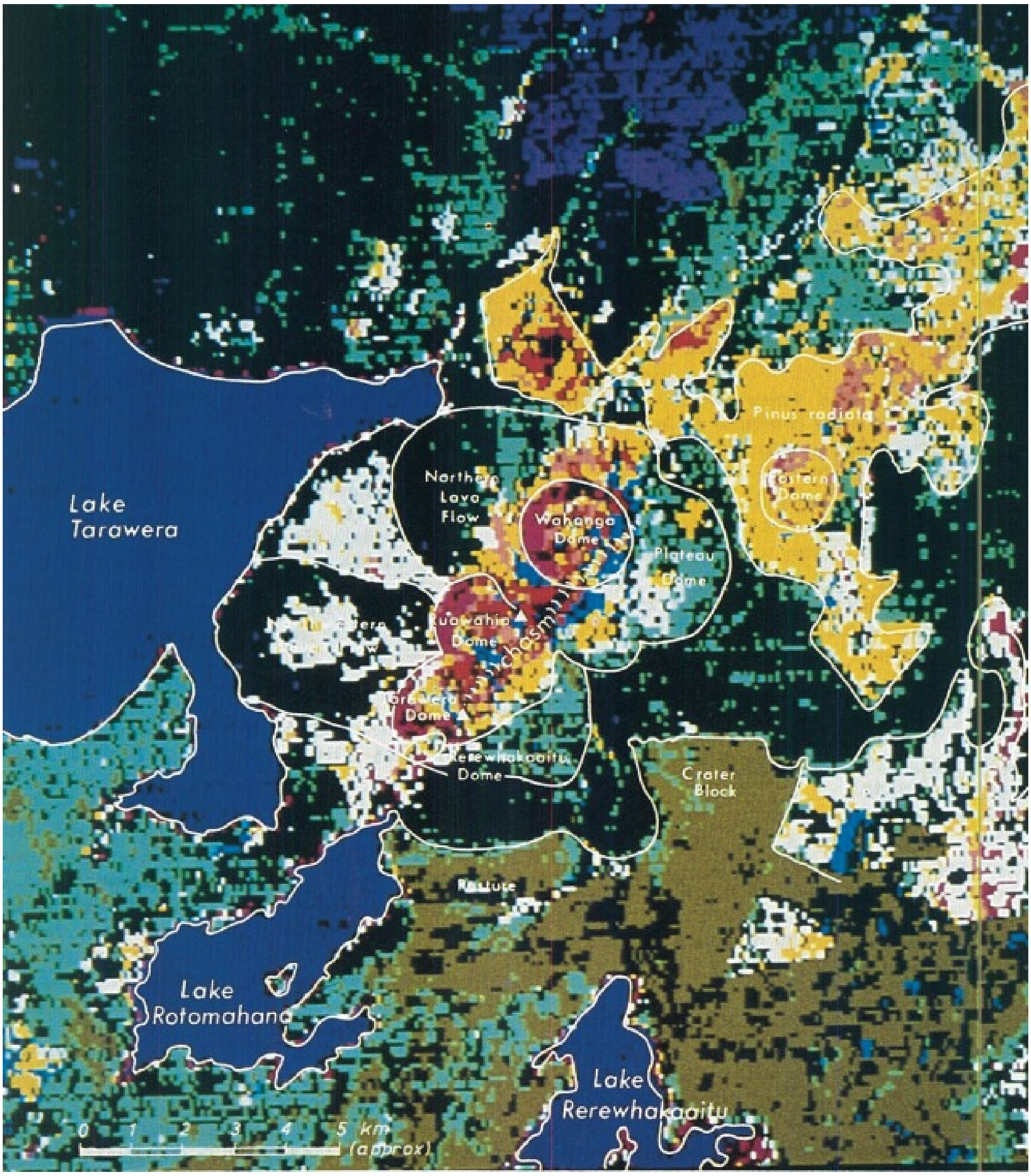

FIGURE 3. *Final map of the Mt Tarawera vegetation, derived from Landsat digital data analysis (B).*

halli), Olearia furfuracea and kanuka. In common with the next forest class (11b.), this class contains east facing slopes of tawa with mangeao *(Litsea calicaris)*.

11b. *Low Reflectance Forest*. This class represents several different forest conditions but all with lower reflectance values, especially in the infrared wavelength bands, than the 'Native Forest' class. Forest on west facing slopes with a similar composition to that of 'Native Forest' is mapped. This class also indicates young exotic pine forest of 4.5 - 6.0 m without crown closure, patches of lower native forest, and the presence of valleys within 'Native forest'. The two classes were combined in the final map (Fig. 2).

11c. *Bright Forest and Sunny Forest*. These two training classes were combined to map kamahi forest on east facing slopes (i.e. high incident light at 9.12 a.m. (NZST).

12. *Dull Forest*. Predominantly a kohuhu--kanuka-kamahi treeland, about 4.5 to 6.0 m high. Up to 30 % of the canopy cover is kanuka and manuka.

13. *Exotic Pine*. This class is dominated by radiata pine *(Pinus radiata),* about 8 m tall with full crown closure.

14. *Pasture*. Areas of clover-ryegrass *(Trifolium repens-Lolium perenne)* grassland in 1975

15. *Water*. The major water bodies of Lake Tarawera, Lake Rotomahana and Lake Rerewhaka-aitu are depicted.

16. *Unclassified*. Areas which are not coloured in either Figure 2 or 3 are unclassified. The radiance values of the pixels concerned did not fit within the ranges of any of the training classes provided. Many of these areas are cliff faces, 'holes', ridge tops or gullies, as well as transitional or variant vegetation types.

Map Accuracy

The vegetation map was tested in the field at two different 'levels' (Anderson *et al.,* 1972) of classification, using the method described previously. Under the higher level scheme, the class descriptions drawn up before testing commenced were adhered to rigorously. Under the second regime, an area was recorded as correctly classified if the classification was meaningful, even if the area did not comply *precisely* with the definition of the class to which it was assigned (Table 2). Using the strict regime, the probability of a pixel being correctly classified with 95 % confidence, was at least 65 0/0, and using the relaxed regime, at least 88 %.

The classification of each pixel should not be accepted uncritically. Because some vegetation classes had overlapping spectral signatures~ some classes substituted for others. For example, misclassifications were found between 'Bare' and 'Mossland', 'Mossland' and Herbfield', 'Tall Manuka' and 'Native Forest', 'Mixed Shrubs' and 'Native Forest', 'Tall Manuka' and 'Kanuka-Manuka', and areas of newly planted (1972-75) pine seedlings were incorrectly classified as 'Herbfield' (yellow area, right edge of Fig. 3). In the latter case, pines were easily separated from true 'Herbfield' areas by their location.

Accuracy of mapping varied between classes. 'Mixed Shrubs' and 'Mossland' occurred in the field in narrow strips and were, therefore, more likely to be inaccurately classified than classes with a clumped distribution. In any class, *groups* of like pixels were classified more reliably than single pixels because edge-pixel values were influenced by neighbouring vegetation types.

Greater subdivision and accuracy existed in the mapping of low cover vegetation compared to that of forest types. In radiance terms, the floristically distinct forest types (kamahi, kamahi-tawa and tawa-kamahi with mangeao) were similar, whereas the lower stature classes, with the additional factor of variation in percentage scoria, were spectrally separable.

Two cluster analyses, using the computer package BMDP:P2M (Dixon and Brown, 1979) were conducted, one using structural, the other floristic variable (Timmins, 1981). The results indicated that the Landsat-derived classification had greater affinities with the structural (height and canopy closure) than the floristic variables of a vegetation stand.

The three forest types were not discriminable except for partial separation on the well-lit, northern slope of Tarawera Ridge (Fig. 3). The physiognomically-derived differences in reflectance of kamahi and tawa were cancelled out by the variety of light conditions on Tarawera.

Classes which were defined in terms of topography and soil, as well as vegetation, were mapped more successfully than those based simply on floristics. A localised example of this was the remarkable congruence between the vegetation boundaries in Figure 2 and Dickinson's (1980) map for the plateau dome.

The Landsat four MSS band parallelepiped classification on Mt Tarawera works well at level I (forest, scrub, low cover, pasture, water) and level II, but subdivisions within these groups were not always accurately classified. 'Herbfield' was the least accurately classified group (Table 2). 'Mossfield', 'Shrubs Sun', 'Kanuka/Herbfield', 'Low Reflectance Forest' and 'Kanuka-Manuka' also had low accuracy figures under the rigorous regime. Most of the class accuracies improved markedy under the more re-taxed testing regime (Table 2). The classification is certainly accurate at level II (Anderson *et al.*, 1972) and in most cases, within acceptable accuracy limits at level III.

EVALUATION AND CONCLUSIONS

The Landsat derived map of Mt Tarawera lacked the detail of ground produced mapping (e.g. Burke, 1964; Dickinson, 1980) due to the physical characteristics of the Landsat data. Furthermore, structural, rather than floristic, variables appeared to be more important to the Landsat classifier. Nevertheless, the macro-vegetation patterns observed during field surveys on Tarawera were clearly displayed. Although, at a more detailed level, the final map was not always strictly correct (Table 2), a boundary on the map always reflected some vegetation change in the field.

All mapping involves arbitrary rules about the placement of boundaries between similar plant communities, a difficulty accentuated in vegetation in a state of rapid change. Landsat objectively made a decision on the basis of spectral reflectance, an integration of a large number of features of a vegetation stand. Even if a completely correct classification was impossible, at least Landsat offered a classification which was consistent, and could be verified by field checking.

The future of multispectral data analysis in New Zealand native vegetation studies lies in preliminary exploration of new areas to indicate localities for future field visits, the mapping of relatively large areas of indigenous vegetation at level II to level III, and for sequential mapping of areas with difficult access.

The full mapping potential of Landsat data was not realised. In larger areas, particularly ones with

TABLE 2. *Analysis of testing results*

Class	Total No. Pixels in Study Area	No. Pixels Checked (n)	No. Pixels Correct (P)	Percent[a] Accuracy	No. Pixels Correct (P)	Percent[a] Accuracy
Bare	460	59	50	74	55	86
Mossland	664	167	88	45	167	100
Tutu and Scoria	929	82	61	64	82	100
Herbfield	2166	241	58	18	233	94
Shrubs/Herbfield	1157	46	34	59	44	89
Kanuka{Herbfield	1311	33	23	51	33	100
Kanuka-Manuka	2372	139	94	59	134	93
Mixed Shrubs	3577	157	133	79	154	95
Shrubs Sun	1800	77	35	33	54	59
Tall Manuka	1800	124	82	57	116	89
Native Forest	6941	63	57	82	57	82
Low Reflect Forest	6171	78	51	54	64	74
Bright Forest	5010	76	63	73	72	89
TOTAL	33201					

Map classification accuracy using strict class definitions is at least 65%, and using relaxed class definitions is at least 88% (with 95 % confidence limits).

[a] Percent accuracy with 95 % confidence limits was calculated using the following formula:

$$(m - 1.65\, e_m) - 1.65\, (s + 1.65\, e_s)$$

where n is the number of samples taken
- p is the number of samples correctly classified
- m is the estimated mean of the distribution
- s is the estimated standard deviation of the distribution
- e_m is the standard error of the estimate of the mean
- e_s is the standard error of the estimate of the standard deviation (Moroney, 1962)...

difficult access, good results can be gained faster by Landsat data analysis than by field work alone. I consider that the most detailed and accurate maps will always come from ground survey, but the time required in most cases does not warrant the extra information gained. Many decisions on the fate of New Zealand's native vegetation resources are made under pressure. Landsat mapping offers a method of acquiring information faster than by conventional methods, without loss of quality and in time to assist in land management decision making.

There will never be any substitute for good field knowledge, both in support of Landsat data analysis and for detailed studies of small areas of native vegetation. But Landsat digital data analysis is valuable when used correctly for the right purpose, e.g. broad scale mapping. It is not the total answer to New Zealand's classification and mapping needs, but used in conjunction with other information sources, Landsat data form an important tool for New Zealand plant ecologists.

ACKNOWLEDGEMENTS

This paper was derived from part of an M.Sc. thesis submitted to the University of Waikato, Hamilton in 1981. I am most grateful to Dr Alan Edmonds for his encouragement and help throughout my study. The Remote Sensing Section, PEL, DSIR, provided much technical support to this research and I thank Drs Ian Thomas and Peter Ellis (PEL) and Miss Vivien Benning (Department of Lands and Survey) for their advice on Landsat digital data analysis procedures. Field assistance was provided by Mr Kerry Hollingsworth. The computer package DOGMA was developed at the Univeristy of California, Santa Barbara and made available at University of Waikato per courtesy of Geography Department, Auckland University. Drs Ian Thomas and Alan Edmonds also made helpful criticisms on drafts of the present paper.

REFERENCES

ANDERSON, J. R.; HARDY, E. E.; ROACH, J. T. 1972. A land-use classification system for use with remote-sensor data. *United States Geological Survey Circular* 671.

ATKINSON, I. A. E. 1962. Semi-quantitative measures of canopy composition as a basis for mapping vegetation. *Proceedings of the New Zealand Ecological Society* 9: 1-8.

BATTY, J. 1977. (unpublished). An evaluation of the various Landsat analytical techniques available in New Zealand with respect to land use – land cover and vegetation mapping. M.Sc. Thesis, University of Auckland, Auckland.

BURKE, W. D. 1964. (unpublished). A study of the vegetation of a part of Mt Tarawera. M.Sc. Thesis, Victoria University of Wellington, Wellington.

CHILD, R. C.; DICKSON, P. 1978. Mapping, land use and environmental studies in New Zealand. *In:* Ellis, P. J.; Thomas, I. L; McDonnell, M. J. (Editors). *Landsat II over New Zealand: monitoring our resources from space*. pp. 281-96. DSIR Research Bulletin No. 221. 450 pp.

COCHRANE, G. R.; BATTY, J. 1978. Thematic mapping: land use and vegetation mapping of the Aupouri Peninsula, Northland, New Zealand, from Landsat. *In:* Ellis, P. J.; Thomas, I. L; McDonnell, M. J. (Editors). *Landsat II over New Zealand: monitoring our resources from space*. pp. 372-83. DSIR Research Bulletin No. 221. 450 pp.

CURTIS, J. 1959. *The vegetation of Wisconsin: An ordination of plant communities*. The University of Wisconsin Press, Wisconsin.

DALE, R. W. 1978. Typing and mapping of the King Country vegetation. *In:* Ellis, P. J.; Thomas, I. L; McDonnell, M. J. (Editors). *Landsat II over New Zealand: monitoring our resources from space*. pp. 435-43. DSIR Research Bulletin No. 221. 450 pp.

DICKINSON, B. R. 1980. (unpublished). The flora and vegetation of the high domes of Mount Tarawera, Rotorua, New Zealand. M.Sc. Thesis, University of Waikato, Hamilton.

DIXON, W. J.; BROWN, M. B. 1979. BMDP-79: Biomedical Computer Programs: P-series. University of California Press, Berkeley.

DRUCE, A. P. 1959. An empirical method of describing stands of vegetation. *Tuatara* 8(1): 1-12.

DRUCE, A. P.; OGLE, C. C. 1972. (unpublished). Vascular plants of Mt Tarawera, 2000-3644 ft. No. 54 (March 1980). 6 pp.

ELLIS, P. J. THOMAS, I. L; McDoNNELL, M. J. 1978. *Landsat II over New Zealand: monitoring our resources from space*. DSIR Research Bulletin No. 221. 450 pp.

HBWISH, M. 1980. How to look at earth from space. *New Scientist* 86(1203): 144-5.

HICKS. D. L 1978. Evaluation of Landsat computer compatible tapes as an aid for vegetation classification on land resource inventory worksheets. *In:* Ellis, P. J.; Thomas, I. L; McDonnell, M. J. (Editors). *Landsat II over New Zealand: monitoring our resources from space*. pp. 354-70. DSIR Research Bulletin No. 221. 450 pp.

LANDGREBE, D. A. 1976. Machine processing of remotely acquired data. *In:* Lintz, J.; Simonett, D. S. (Editors). *Remote Sensing of the Environment*. pp. 349-73. Addison-Wesley, Massachusetts.

LANDGREBE, D. A. 1973. An evaluation of machine processing techniques of ERTS-l data for used applications. *Proceedings of the Third Earth Resources Technology Satellite-1 Symposium* I: 47-74.

McDoNNELL, M. J. 1978. Digital image rectification and enhancement on a minicomputer: analysis of results. *Proceedings of the Twelfth international Symposium on Remote Sensing of Environment* 1978: 1687-95.

McDONNELL, M. J. 1979. Computer image processing and production at PEL *Proceedings of the Tenth New Zealand Geographical Conference and Forty-Ninth ANZAAS Congress (Geographical Sciences)* 1979: 274-5.

MCGREEVY, M. G. 1978. Indigenous forest assessment. *In:* Ellis, P. J.; Thomas, I. L; McDonnell, M. J. (Editors). *Landsat II over New Zealand: monitoring our resources from space*. pp. 334-8. DSIR Research Bulletin No. 221. 450 pp.

MOODY, G. 1979. (unpublished). Agricultural analysis from Landsat, a case study: The Waitaki Plains, South Island, New Zealand. M.A. Thesis, University of Auckland, Auckland.

MORONEY, M. J. 1962. *Facts from figures*. Penguin Books Ltd, Middlesex.

STRACHAN. D. 1977. Vegetation mapping using Landsat II data: An example from East Taupo. *Auckland Student Geographer* 8: 53-8.

SWAIN, P. H. 1978. Fundamentals of pattern recognition in remote sensing. *In:* Swain, P. H.; Davis, S. M. (Editors). *Remote sensing: The quantitative approach*. pp. 136-87. McGraw-Hill, New York. 396 pp.

SWAIN, P. H.; DAVIS, S. M. 1978. *Remote sensing: The quantitative approach*. McGraw-Hill, New York. 396 pp.

THOMAS. I. L. 1979. Cartography from landsat: Introducing the DSIR computerised land use mapping package. *Proceedings of the Tenth New Zealand Geographical Conference and Forty-Ninth ANZAAS Congress (Geographical Sciences)* 1979: 276-8.

THOMAS, I. L; BENNING, V. M.; BENNETIS, R. L 1980. Land-use applications of Landsat. *New Zealand Agricultural Science* 14(4): 169-84.

THOMAS, I. L; McDONNELL, M. J.; ELLIS, P. J.; FOWLER, A. D.; CHILD, R. C.; NANKIVELL. C. T.; MASON, R. S. 1978. Monitoring some aspects of New Zealand's agricultural programme with Landsat: A preliminary report. *In:* Ellis, P. J.; Thomas, I. L.; McDonnell, M. J. (Editors). *Landsat II over New Zealand: monitoring our resources from space*. pp. 163-230. DSIR Research Bulletin No. 221. 450 pp.

TIMMINS, S. M. 1981. (unpublished). The vegetation of Mt Tarawera, Rotorua, New Zealand. A study using Landsat digital data. M.Sc. Thesis, University of Waikato, Hamilton.

U.S. GEOLOGICAL SURVEY. 1979. *Landsat Data Users Handbook*. U.S. Department of Interior, Arlington, Virginia (revised edition).