Use of satellite imagery to map and monitor vegetation in New Zealand

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Abstract

Land resource and environmental decision makers require quantitative information on the spatial distribution of vegetation types and their condition, and changes in these over time. Such vegetation mapping and monitoring is often required to be undertaken quickly. Remotely-sensed satellite imagery, in conjunction with other data sources, have been used to satisfy this need.

This paper describes the uses of satellite imagery by reference to three regional mapping projects in New Zealand. The first project describes the use of Landsat TM imagery to map forest, scrub, pastural and cropping vegetation types. The second project concerns the innovative use of SPOT imagery, colour infrared aerial photography and ground observations to map percent vegetation cover for a degraded rangeland. The remaining project combines NOAA AVHRR imagery with daily dairy farm production data, as a means of monitoring sustainability and productivity of pastoral land use.

1.0 Introduction

In New Zealand the concept of environmental monitoring and land-use sustainability feature prominently in legislation, namely the 1991 Resource Management Act (RMA), and policy (Ministry for Environment 1995). The RMA requires local government natural resource management agencies to ensure that land use is sustainable, and that any effects of land use practices are environmentally acceptable. To aid RMA compliance with respect to sustainable land management, land resource and environmental decision makers require quantitative information on vegetation types and condition, and changes in these over time.

Satellite imagery is ideally suited to the task of quickly providing vegetation information over large areas (Congalton *et al.* 1993, Townshend 1992, Ehrlich *et al.* 1994). Since 1982, imagery has been available in which a substantial proportion of the main vegetation types can be mapped and monitored, especially in rural areas. Principal sources of data include the high spatial resolution imagery from Landsat's Thematic Mapper (TM) and SPOT's High Resolution Visible (HRV) sensor. Numerous examples of applications of these data can be found in the literature: tropical forest classification in Mexico (Garcia and Alvarez 1994); monitoring forest defoliation by insects in the USA (Muchoney and Haack 1994); agricultural land use classification in France (Hill and Megier 1988); mapping vegetation changes on a coastal environment in New Zealand (Wilde 1992); and monitoring and modelling semi-arid landscape responses to climate change in the USA (Yuhus and Goetz 1994). For these applications the detailed view provided by the TM and SPOT HRV sensors has been essential. In parallel with the expanding range of land resource applications of these data, there has, in recent years, been interest in the use of coarse spatial resolution data from sensors such as the National Oceanographic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR). Due to their daily coverage, synoptic overview and (low) data volumes AVHRR data are used increasingly for global and regional land-cover studies principally(Ehrlich *et al.* 1994).

This paper describes the uses of satellite imagery in New Zealand for environmental and land sustainability purposes, by reference to three regional projects (see Fig 1). The first project describes the use of Landsat TM imagery and ancillary data from a geographic information system (GIS) to map forest, scrub, pastural and cropping vegetation types (see Section 2.0). The second project concerns the innovative use of SPOT imagery, colour infrared aerial photography and ground observations to map percent vegetation cover for a degraded rangeland (see Section 3.0). The remaining project (Section 4.0) combines NOAA AVHRR imagery with daily dairy farm production data, as a means of monitoring sustainability and productivity of pastoral land use.

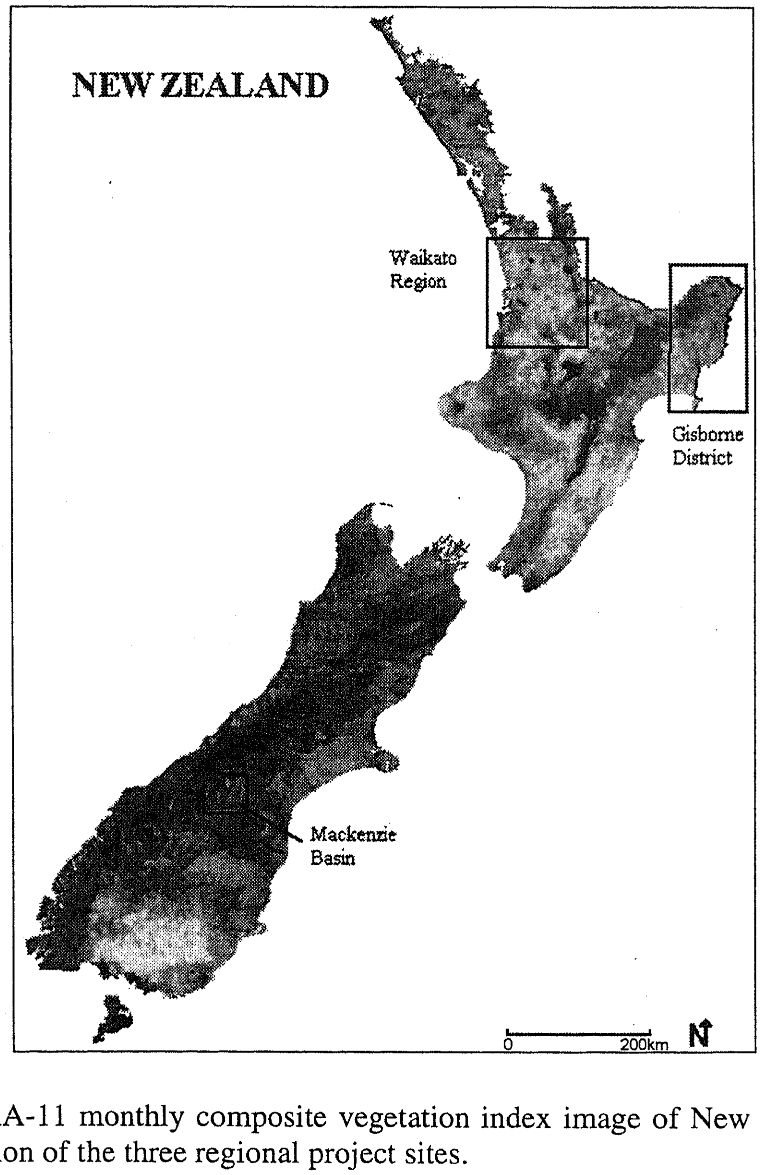

Figure 1. NOAA-11 monthly composite vegetation index image of New Zealand showing location of the three regional project sites.

2.0 Large area vegetation mapping using Landsat TM imagery

National and local debate over a Government-sponsored forestry scheme, designed to prevent erosion in the 830 000 hectare Gisborne district (see Fig 1), highlighted the need for up-to-date information on vegetation cover. Some of the debate concerned a major landowner wanting to take advantage of monetary incentives to convert erosion-prone land to production forestry. Much of the land was in various stages of reversion to original indigenous forest, and environmental groups argued that the incentive scheme should not be applied in this case as the reverting vegetation cover already prevented erosion. To help resolve this issue, land management policy makers wanted up-to-date, quantitative information on vegetation cover in the district, with a special focus on areas of reversion characterised by kanuka (*Kunzea ericoides*) and manuka (*Leptospermum scoparium*).

Four maps of vegetation, at a scale of 1:100 000, were produced by automatically classifying January 1993 Landsat TM imagery. By reference to information from earlier vegetation surveys, 100 training polygons were used to characterise spectral signatures. A maximum likelihood classifier was used on all seven TM bands to map eleven vegetation types. To identify gross classification errors, the classified imagery was compared with a rasterised version of existing vegetation information from a geographic information system (GIS) database. The existing vegetation information was 20 years old. Through field checking the discrepancies were confirmed as either real (changes) or errors in classification. Correction of the errors increased the overall classification accuracy from 84 per cent to 90 per cent (Dymond *et al.* in press).

In addition to the vegetation maps, land planners also required information on the distribution of vegetation according to land use suitability. The vegetation maps were intersected with land suitability data from a national land resource inventory GIS database (Eyles and Newsome 1990), and the areas of each vegetation class on three critical types of land suitability were calculated (see Table 1). Although 90 per cent accuracy is high enough to permit the calculation of vegetation areas and to achieve an adequate representation of regional vegetation patterns, it is not considered high enough to permit the digital vegetation map to be used as a vegetation database where point queries are important, as approximately 10 per cent of the point queries would be totally wrong. Errors associated with point queries should be less than 5 per cent, ideally less than 2 per cent. In such cases, detailed field surveys of vegetation would be required.

3.0 Mapping changes in percent vegetative cover using SPOT imagery

The semi-arid Mackenzie Basin in the central South Island (see Figure 1) has significant land degradation attributed to drought, an explosion in rabbit numbers, and overgrazing by sheep (Cuff and Dymond 1994). A Rabbit and Land Management Programme was introduced by Government as the institutional response to these environmental problems. Monitoring systems were required to determine the effectiveness of this programme. Indicators of change have been rabbit numbers and traditional vegetation surveys undertaken annually at a large number of sites (c. 300). Remotely-sensed satellite data have also been used as a means to monitor regional vegetation changes.

Vegetation class	Land suitable for pastoral farming	Land suitable for conservation farming or production forest	Land suitable for protection forest
Fernland	170	1160	150
Kanuka/manuka	18700	38900	2140
Secondary forest	10500	16500	2460
Podocarp forest	120	120	0
Primary forest	20000	36700	35800
Beech forest	2900	7300	9900
Subalpine vegetation	90	150	870
Exotic forest	28500	76800	3100
Pasture	239600	227800	6100
Bareground	14900	7900	1340
Water	50	0	6
Undefined	2310	14700	110

Table 1. Areas in hectares of vegetation classes on land suited for three critical land uses in the Gisborne district.

Dymond *et al.* (1992) developed a technique, using SPOT multispectral imagery, to map percent vegetative cover in the Mackenzie Basin. This technique relied on the establishment of a relationship between normalised difference vegetation index (NDVI) and percent vegetative cover. This relationship was derived from ground cover measurements from 20 60m x 60m quadrats which represented the soil and vegetation patterns in the basin. Specially flown colour infrared aerial photographs, which covered the quadrats, were used to locate the quadrats in the SPOT images. The relationship between NDVI and percent vegetative cover was expressed as a simple non-linear calibration curve (see Fig 2)

$$C=50\tanh(6.1(NDVI-0.22))+50$$

where C is percent vegetative cover and $\tanh(x)=(\exp x-\exp(-x))/(\exp x+\exp(-x))$. The spread of the quadrat points about the calibration curve gives the accuracy of a percentage vegetative cover predicted from the NDVI. In the linear part of the calibration curve, the upper and lower prediction limits (80 per cent confidence interval) are ±15 per cent cover.

Using this technique, Cuff and Dymond (1994) mapped percent vegetative cover in the basin, for 1987 and 1990. The February 1987 imagery was SPOT multispectral, and the January 1990 imagery was Landsat TM. Comparison of the 1987 and the 1990 percent vegetative cover images was used to produce a 1:50 000 scale land cover change map. Analyses of the satellite images provided overall trends in vegetative ground cover as well as the ability to determine the change at the pixel level. An assessment of the change indicated a four per cent decrease in overall vegetative cover, which was consistent with the perceived decline in land condition during this period. This confirmed the usefulness of this satellite technique to provide an overview of vegetative cover changes.

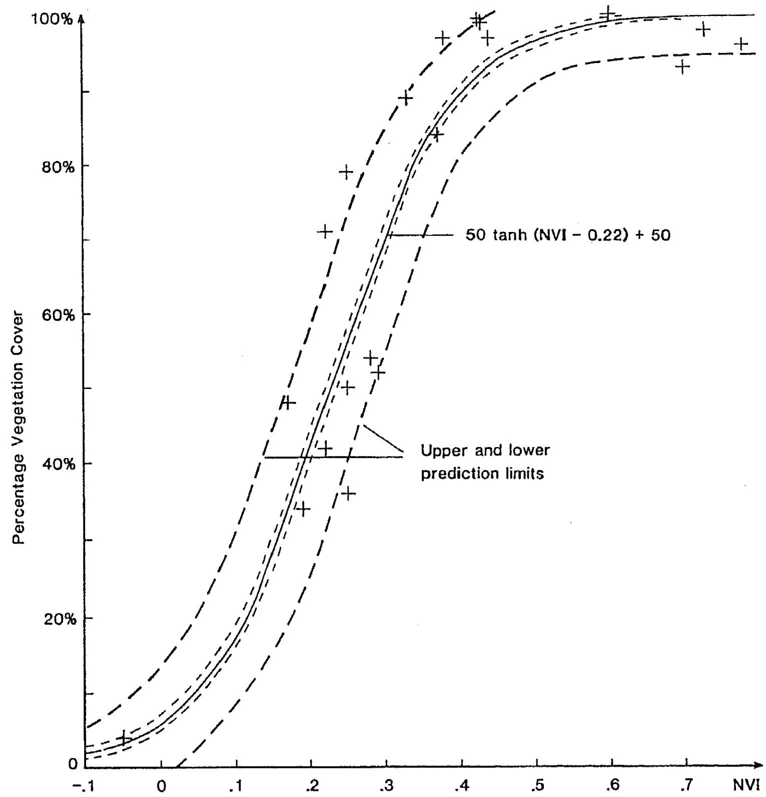

Figure 2. Calibration plot of per cent vegetation cover versus NDVI. Crosses indicate quadrat plotting positions.

4.0 AVHRR imagery to monitor sustainability and productivity of pastoral land use

A number of land management and environmental agencies in New Zealand are concerned about land-use sustainability. The productive capacity of the land is inescapably linked to its biophysical condition. The condition of vegetation - its biomass and photosynthetic activity - provides a direct measure of biophysical sustainability in managed environments. NOAA AVHRR data have been used to improve the monitoring of vegetation condition and productivity (Brown and Stephens 1995). Containing a large number of dairy farms, the Waikato region (see Fig. 1) was used for the project.

The use of NOAA AVHRR data in agricultural studies gives rise to two problems: the large ground area covered by each pixel relative to field size, and the collection of adequate ground data. In this study, actual pasture productivity was not measured directly. Instead, daily milkfat production from dairy farms was used as a productivity surrogate. The use of milkfat production data provides a temporal and spatial resolution that cannot be logistically obtained by pasture-cut samples. As dairy farming operations in New Zealand are usually located in extensive areas of contiguous pastoralism, the pixel size versus size of land unit problem is overcome.

The AVHRR imagery was transformed to radiance, corrected for atmospheric effects using the 5S code (Tanré *et al.* 1987), and resampled to 1km spatial resolution. An NDVI image was then calculated. Images of AVHRR channels 1 and 4 were also produced for a cloud identification procedure. In this procedure, images having a thick cloud layer are visually identified and discarded. For the remaining imagery, study sites (within the Waikato region) were rated for the effects of scattered cloud using the range in channel 1 pixel values as the criterion. A mean NDVI was then determined for each site, for each cloud-free day, and plotted against milkfat production (see Fig 3). For the 1992/1993 lactation, milkfat production and NDVI exhibited a similar pattern in the study sites - both peaking in Spring and declining over Summer, with two other smaller plateaus and rises (attributable to rainfall events). These results show a probable causal relation between the AVHRR-derived NDVI and milkfat production. Farm production models will be needed to quantify the relationship further. We are presently using successive years NOAA AVHRR data to improve the relationship between pasture and milk production, in order to monitor land productivity. This work also involves partitioning the AVHRR imagery with ancillary GIS data, with which homogeneous land cover types are identified.

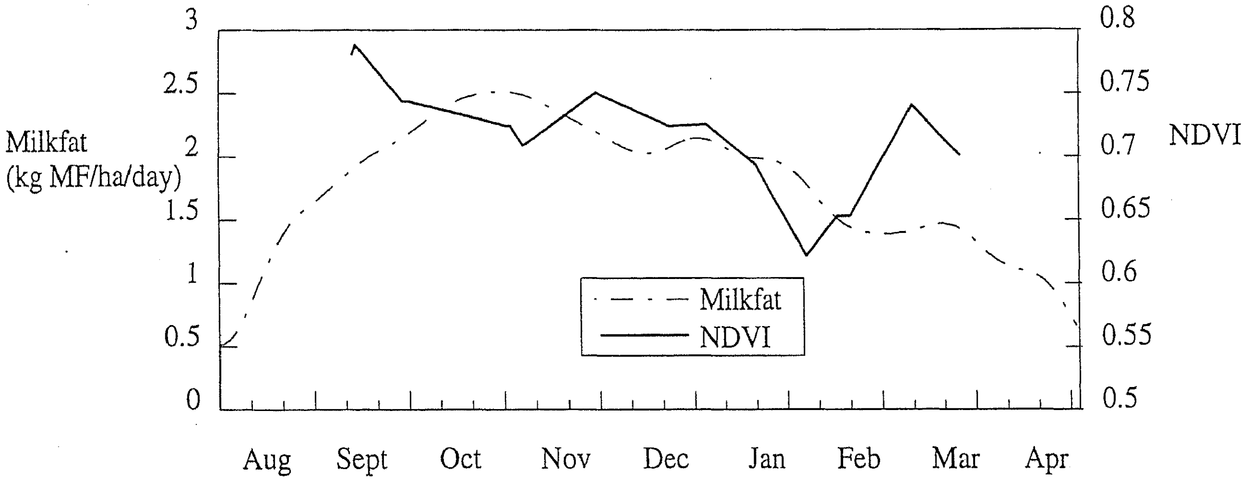

Figure 3. Milkfat production and NOAA NDVI for the 1992-93 lactation for one of the sites in the Waikato region.

5.0 Summary

In these three vegetation mapping projects, remotely-sensed satellite imagery, in conjunction with other data sources, has been used to help land resource and environmental decision makers in New Zealand who have required quantitative information on vegetation types and condition, and changes in these over time.

A range of ancillary data sources was used to help classify and calibrate satellite imagery. The data used varied according to the nature of environmental issue; the availability and form of existing data; the time frame for the project; the availability and spatial and temporal resolution of remotely-sensed imagery; and the type of information required for land resource and environmental planning.

SPOT and Landsat TM images are suitable for providing vegetation baseline and vegetation change information in a quantitative manner. Mapping scales range from 1:50 000 to 1:100 000. However, the timeliness of information delivery depends on availability of suitable imagery: New Zealand does not have an earth resource satellite receiving station, so is presently dependent on the SPOT tape recorder to obtain high spatial resolution data. TM data has not been available since 1994.

Errors associated with such vegetation mapping are acceptable for calculating vegetation areas and achieving an adequate representation of regional vegetation patterns and changes, but are too high to produce databases where point queries are important. NOAA imagery requires additional pre-processing (atmospheric correction, cloud-removal and compositing (over durations of 10-30 days)) before it can be considered useful for regional and national monitoring of the sustainability and productivity of pastoral land use.

Despite the issues of mapping accuracy and imagery availability in New Zealand, the use of remotely-sensed satellite imagery provides the only cost-effective means to obtain useful land cover data for large areas. The promise of soon-to-be-launched satellite systems with sensors recording in the visible, near infrared and mid-infrared, and with on-board tape recorders augurs well for the future operational use of remotely-sensed data for vegetation mapping and monitoring.

6.0 Acknowledgments

Much of the research reported here was funded through the New Zealand Foundation for Research, Science and Technology contracts CO9222 and CO9419. We gratefully acknowledge the assistance of the following agencies: AnchorProducts NZ Ltd, Livestock Improvement, Ministry of Forestry, Department of Conservation, Canterbury Regional Council, Gisborne District Council, and Hikurangi Forest Farms.

7.0 References

Brown, L.J., P.R. Stephens, "Monitoring pasture productivity in New Zealand - an investigation using NOAA-11 AVHRR data and dairy farm milk fat production", *International Journal of Remote Sensing*, Vol 16(5), pp.967-972, 1995

Congalton, R.G., K. Green, and J. Tepley, " Mapping old growth forests on national forest and park lands in the Pacific Northwest from remotely sensed data", *Photogrammetric Engineering and Remote Sensing,* Vol 59, pp.529-535, 1993

Cuff, J.R.I., J. Dymond, "Satellite data to map changes in vegetative cover in the Mackenzie Basin", Proceedings 4th National Remote Sensing and GIS Workshop, April 7-8 1994, Landcare Research, Palmerston North, pp.55-64, 1994

Dymond, J., P.R. Stephens, P.F. Newsome, and R.H. Wilde, "Percentage vegetation cover of a degrading rangeland from SPOT", *International Journal of Remote Sensing*, Vol 13 (11), pp.1999-2007, 1992

Dymond, J.R., M.J. Page, and L.J. Brown, "Large area vegetation mapping in the Gisborne district, New Zealand, from Landsat TM", *International Journal of Remote Sensing*, in press

Ehrlich, D., E. Estes, and A. Singh, "Applications of NOAA-AVHRR 1 km data for environmental monitoring", *International Journal of Remote Sensing*, Vol 15(1), pp. 145-161, 1994

Eyles, G.O., P.F. Newsome, "A decade of experience of using a New Zealand GIS", *New Zealand Geographer,* Vol 46, pp.43-47, 1990

Garcia, M.C., R. Alvarez, "TM digital processing of a tropical forest region in southeastern Mexico", *International Journal of Remote Sensing*, Vol 15(8), pp.1611-1632, 1994

Hill, J., J. Megier, "Regional land cover and agricultural area statistics in the Department Ardeche, France, by use of Thematic Mapper data", *International Journal of Remote Sensing*, Vol 9, pp.1573-1596, 1988

Ministry for Environment, "A sustainable land management strategy for New Zealand. A discussion paper", New Zealand Ministry for the Environment, Wellington, 21p., 1995

Muchoney, D.M., B.N. Haack, "Change detection for monitoring forest defoliation", *Photogrammetric Engineering and Remote Sensing*, Vol 60 (10), pp.1253-1251, 1994

Tanré, D., C. Deroo, P. Duhaut, M. Herman, J.J. Morcrette, J. Perbos, and P.Y. Deschamps, "Simulation of the satellite signal in the solar spectrum (5S)", Laboratoire d'Optique Atmosphérique, Université des Science et Techniques de Lille, Cedex, France, 1987

Townshend, J.R.G., "Land cover", *International Journal of Remote Sensing*, Vol 13 (6 & 7), pp.1319-1328, 1992

Wilde, R.H., "Mapping changes in vegetation and bare ground from historical aerial photographs and satellite imagery", Proceedings of 6th Australian Remote Sensing Conference, Wellington, New Zealand, Vol 2, pp.108-119, 1992

Yuhus R.H., A.F.H. Goetz, "Monitoring and modelling semi-arid landscape response to climate change", Proceedings 1994 International Geoscience and Remote Sensing Symposium, California, USA, August 8-12, Vol 2, pp.1036-1038, 1994