The New Zealand land cover database: A pilot scheme and a forestry perspective

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ABSTRACT

A major project has been proposed to develop a New Zealand-wide land-cover database, generated primarily from satellite imagery. A pilot investigation of the viability, methods, costs and benefits of the project is described. This involved classification of a Landsat TM image of part of the central North Island into 15 land-cover types.

A subsequent study was undertaken to compare areas of planted and natural forest in the Taupo District derived from the Landsat TM image with existing maps and databases of forest information. Reasons for differences between satellite image classification data and existing records are considered, and suggestions made for the rationalistion of further validation of satellite imagery classification.

BACKGROUND

In 1991 The Ministry of Forestry (MOF) instigated a study (White *et al.*, 1992; Thompson, 1993) to investigate the feasibility of using satellite imagery for forest resource mapping and monitoring within New Zealand. This was seen as a possible solution to their requirement for a more accurate, complete and up-to-date forest cover description.

MOF's areas of responsibility include obtaining the maximum value from production forestry for New Zealand and ensuring the sustainable management of natural forests. It also advises Government and regional authorities on resource planning, and expected transport and infrastructure needs resulting from developments in the forestry sector. To perform its tasks effectively, MOF needs access to data on the current extent and distribution of forested areas throughout New Zealand. It is difficult to maintain up-to-date information on forest cover, especially now that extensive planting by small forest owners is taking place.

Due to restructuring in the forestry sector, records of natural forest distribution have not been updated and often reflect the situation of 20 to 30 years ago. The availability of accurate estimates would have significant benefits for MOF as well as for many other land-management organisations.

MOF was assisted in its satellite imagery study by Landcare Research New Zealand Limited (Landcare), the Department of Survey and Land Information (DOSLI), and the New Zealand Forest Research Institute Limited (NZFRI). Using Landsat Thematic Mapper (Landsat TM) imagery of a suitable test region, the study confirmed that the extent of planted and natural forest could be reliably determined, although some limitations of the technology were noted. These included inability to correctly identify areas planted within the previous three-five years (depending on treatment), and the negative effect of low winter sun angles on classification accuracy. It was concluded, however, that space-borne sensors were a cost-effective source of data, suitable for monitoring and updating forest information (White *et al.*, 1992).

The general success of this study led MOF to suggest to DOSLI that this approach for mapping a broad range of land-cover types should be adopted at a national level, and that updates be generated at regular intervals. MOF surmised that publicly-funded coordinated mapping would be in the national interest as it would encourage cooperation between agencies and reduce duplication of effort. Data would be accessible to more organisations through a cost-effective option for all involved.

DOSLI agreed to coordinate a pilot scheme based on the MOF proposal (Thompson, 1993) and were supported by other interested organisations which formed a consortium of 'sponsor agencies'. As the classification process for the pilot scheme neared completion, MOF asked NZFRI to produce a forest-cover map using the new Land-cover Database (LCDB) data prepared by DOSLI. The LCDB now contains land-cover data for the full image area shown in Figure 1. MOF also required comparisons of this data with existing forest-cover maps and records.

The procedures used and results obtained for the pilot scheme and for the forest cover comparison are described in this paper.

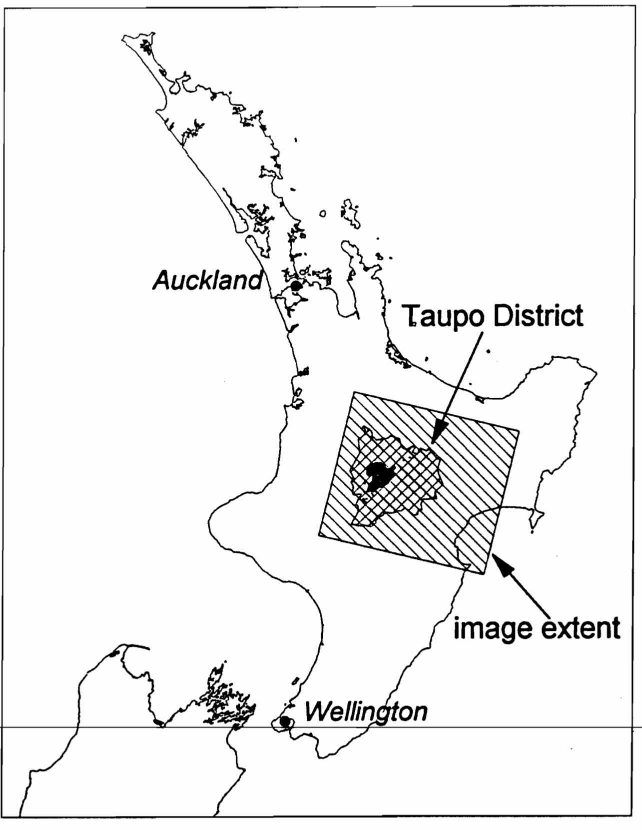

Figure 1: Area of the Central North Island covered by the Landsat image.

THE LCDB PILOT SCHEME

Introduction

Working in collaboration with the consortium, DOSLI prepared a detailed proposal for the pilot scheme. DOSLI would be responsible for obtaining an orthorectified image and classifying

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it into selected cover types. Consortium members were to provide assistance with interpretation of the imagery and validation. Costs were to be shared equally among all members. The proposal contained a list of 15 land-cover classes falling into three broad categories (Table 1). The scheme had three objectives:

- To identify the most effective and economic methods for classifying the imagery to a defined level of accuracy.
- To modify the list of land-cover classes so that only those that are clearly identifiable are included.
- To determine costs involved in obtaining and processing the data.

Table 1: Land-cover classes

Artificial landscape	Cultivated landscape	Natural landscape
Urban areas	Grasslands	Grasslands (Tussock)
Quarries/Dumps	(Improved pasture)	Scrublands
Recreation areas	Croplands	Natural forest
	Orchard/Horticulture	Bare ground
	Planted forest	Inland wetlands
	Shelterbelts	Coastal wetlands
		Coastal sands

Methods

A Landsat TM image of the central North Island, acquired in December 1990 (see Fig. 1 for coverage) was orthoregistered to the New Zealand Map Grid (NZMG) coordinate system using a 100 m Digital Terrain Model. The image covered 170 x 185 km and initially had pixels covering 30 m x 30 m but was resampled so that each pixel represented an area of 25 m x 25 m on the ground. The image had a planimetric accuracy of ± 20 m (i.e. 90% of all points fell within 20 m of actual position) and the minimum land-cover area to be recorded was set at 1 ha. These accuracy parameters accord with the standards used by DOSLI for their 1:50,000 scale topographical map (Infomap 260) series (DOSLI, 1994).

Initial efforts in developing an extraction methodology focussed on the use of automatic classification for all land-cover types. Various image-processing techniques were tested, but none provided satisfactory accuracy. This was often due to the effects of shadow from terrain relief and 'mixels' (where the reflectance of a pixel was affected by more than one land-cover type). Methods were developed to combine automated classification with manual interpretation in an attempt to obtain acceptable accuracy for minimum cost.

It was concluded that using image-processing software offered few advantages over manual data-extraction methods.

The most cost-effective technique involved printing the Landsat TM image at 1:25,000 (using bands 4, 5 and 3 (RGB)) and tracing the boundaries of land-cover classes onto stable drafting film. The tracings were scanned, and the resulting linework was vectorised and overlaid on the original image using a Geographical Information System (GIS)[1]. The land-cover polygons were classified manually by interpretation of the image with the aid of topographical maps and known ground data.

Preliminary validation of classification results was performed by assessment of actual land-cover types at 405 randomly selected 1 ha sample sites. Reference site data were obtained from site visits and photo-interpretation. An error matrix indicating the accuracy of classification at the sample sites was produced and summarised by land-cover type.

Expected costs for development of a national land-cover database (image purchase, mapping, data storage and output preparation) were calculated.

1 *Intergraph MGE from Intergraph Corporation.*

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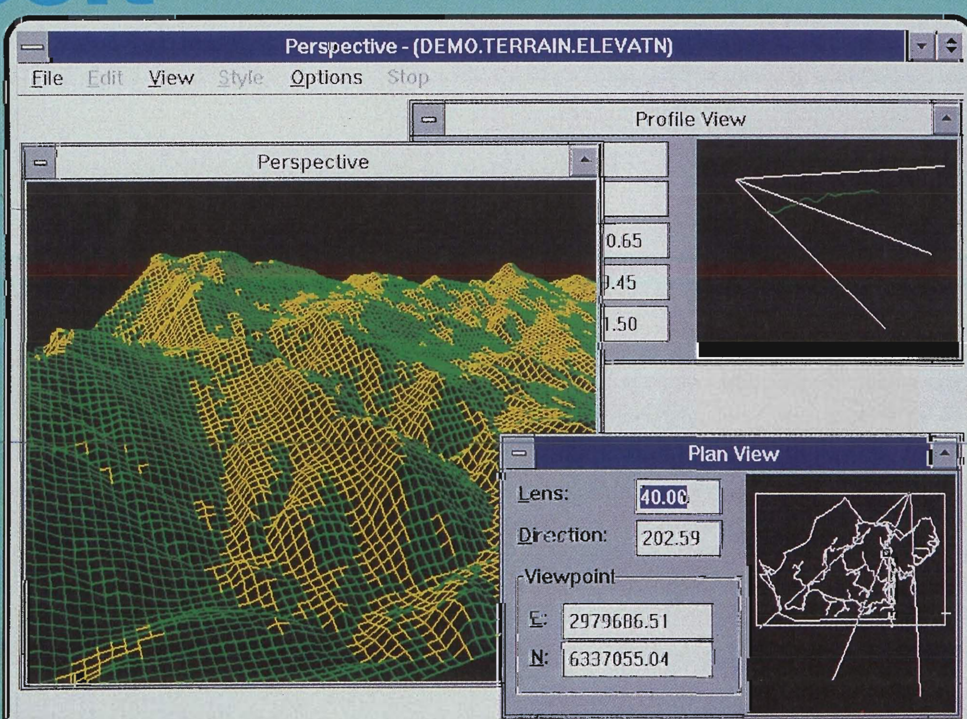

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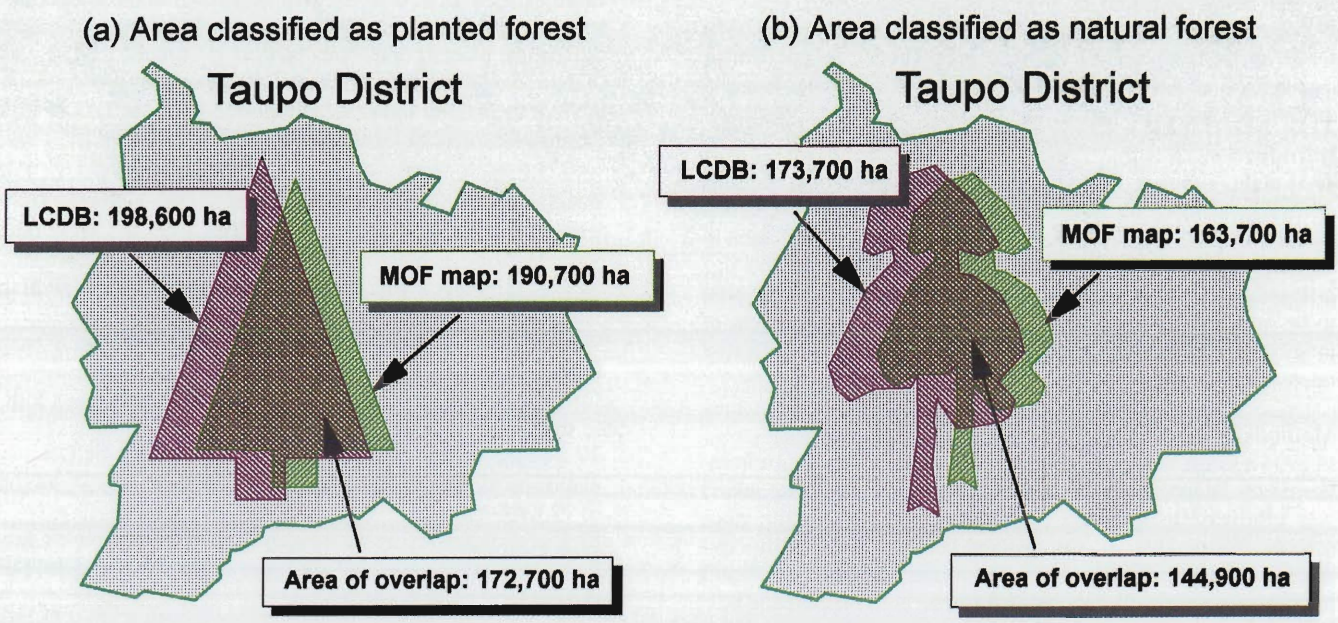

Figure 3: Summary of comparisons between the LCDB and MOF maps.

Results and Discussion

A summary of the error matrix (Appendix I) is given in Table 2. For a known land-cover type at a site, the term 'Producer's accuracy' was used to indicate the probability that it was classified correctly on the land-cover map. The term 'User's accuracy' was used to indicate the probability that a sample area on the map described what was actually on the ground. The overall accuracy was 90% (364 correct classifications from 405 sample sites). The inclusion of confidence limits would indicate the significance of these results (Dozier and Strahler, 1983), but these have not yet been calculated.

The only refinement considered necessary in the list of land-cover classes (Table 1) was the combination of Grasslands and Croplands from the Cultivated landscape category into a new "Pasture" class. This was dictated by the dynamic nature of croplands, and difficulty frequently experienced in separating them from grasslands.

Table 2: Summarised LCDB accuracy assessment

Classification	Sites	Producer's accuracy (%)	User's accuracy (%)
Urban	18	94	85
Quarries and Dumps	3	100	100
Recreational	9	77	87
Pasture (ex Grass & Crop)	74	90	89
Horticulture	11	90	83
Planted forest	77	92	94
Grasslands (Tussock)	32	81	89
Scrublands	76	86	88
Natural forest	74	90	89
Bare ground	24	95	88
Inland wetlands	5	100	100
Coastal sands	2	100	100

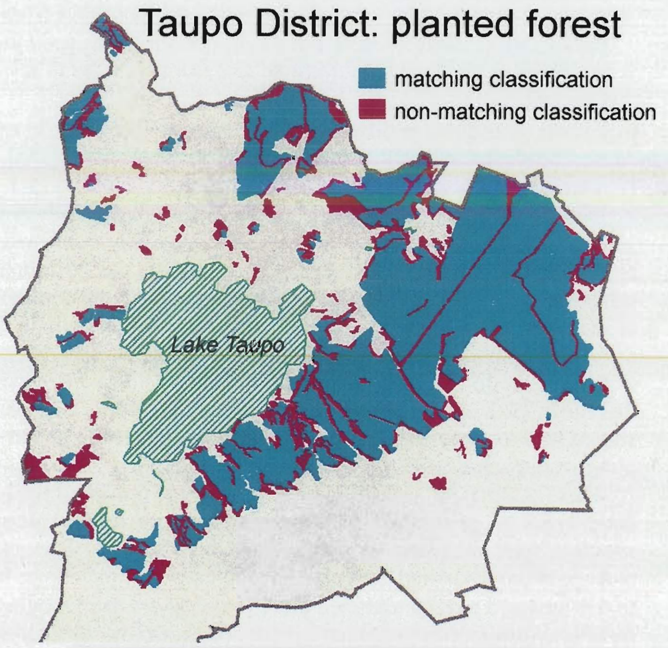

Figure 2: Comparison between LCDB and MOF map.

Classifications were usually accurate in areas of spatial homogeneity where class boundaries were distinct. Less accurate classification occurred along urban fringes due to the heterogeneous nature of the data. Similarly, difficulties occurred with the identification of wetlands which could only be reliably located with the aid of existing topographical maps. The project determined that the identification of shelterbelts and other linear vegetation patterns was unreliable, as only 20% of shelterbelts on existing topographical maps were identified from the imagery.

It was estimated that a national land-cover database (based on 25 Landsat TM images) would cost approximately 1.4 million NZ dollars and could be completed within five years. The development of change-detection and database-updating procedures would have to be completed in that period to enable updates to be made from newer images.

With rapid technological development in remote sensing and image processing, it will be necessary to keep the project flexible, with minimal dependence on any one method or data source. Loss of access to Landsat 5 data and the failure of Landsat 6 emphasised the need for this approach.

Investigations to determine whether the required land-cover classes can be identified from SPOT imagery[2] are currently in progress. The effects of a change in data supplier on project costs

2 *SPOT satellite series developed by the French space agency CNES*

are also being assessed.

Now that the LCDB pilot scheme objectives have been achieved, it is up to the sponsoring agencies to coordinate resources to enable the project to continue at a national level.

THE FORESTRY PERSPECTIVE STUDY

Introduction

The validity of maps derived from remotely-sensed data depends on thoroughness of verification with ground information (Justice and Townshend, 1981). Adequate resources must be allocated to the acquisition of reference data. Validation costs could be significantly reduced if existing data were used to stratify the area to be sampled. (Stratification involves subdividing the area of interest into smaller units, which can be sampled at different intensities (Cochran, 1977).)

Methods

In 1994 a forest-cover map of the Taupo district (the area administered by Taupo District Council: 638,000 ha excluding lakes) was produced using the LCDB data generated in the pilot scheme. Taupo District was selected because it was fully covered by the Landsat TM image used in the scheme (Fig. 1) and has large areas of well-documented forest, both planted and natural.

Boundaries for planted and natural forest areas and scrublands were extracted from the LCDB data and imported into a GIS[3] (Digital Resource Systems, 1992). Records of forest cover were also obtained from three other sources. The first was the National Exotic Forest Description (NEFD) (MOF, 1993), a textual database of information from forest owners which contained the extent of planted forest within each local authority area. The second was a national map of planted and natural forest cover derived from New Zealand Forest Service 1:250,000 Conservancy maps, and updated by MOF using the NEFD and other in-house sources, referred to as the "MOF map" for this study. The third source was Forest Class maps portraying the distribution of natural forest types throughout New Zealand. These were compiled during the 1970s from data collected during the '50s and '60s. Several of the maps have been reproduced in digital form, but approximately half of the forest class data for the Taupo district had to be digitised for this study.

Using the GIS, maps of earlier data were overlaid with the LCDB, and the areas of matching and non-matching classification were identified. Area values were rounded to the nearest hundred hectares due to approximations made when collecting the data.

Comparison of the LCDB data with earlier records allowed division of the area into three categories:

1: Where the LCDB matched earlier records of forest cover type.
2: Where either the LCDB or earlier records showed one forest type, and the other had a different forest type, or another cover type entirely.
3: Where no forest type was recorded on either the LCDB or earlier records.

Results and discussion

The area of planted forest in the Taupo District calculated from 1991 NEFD figures was 187,800 ha, while that derived from the 1990 Landsat TM image was 198,600 ha. The difference is small, but does not take into account the differences in the locations of forests represented in these databases.

If the proposed national LCDB goes ahead, then it will be used to provide a spatial component to the NEFD.

A comparison of the areas classified as planted forest in the LCDB and the MOF map is shown in Figure 2. Results of this comparison, summarised in Fig. 3, indicated that:

- From the LCDB, 31% of the total land-cover in the Taupo district was classified as planted forest, and 27% as natural forest.
- 87% of the planted forest area identified from the LCDB was classified as planted forest on the MOF map.
- 83% of the natural forest area identified from the LCDB was identified as natural forest on the MOF map.
- 85% of the total forest cover identified from the LCDB matched the forest-cover types on the MOF map.
- 91% of the planted forest area identified from the MOF map was classified as planted forest in the LCDB.
- 89% of the natural forest area identified from the MOF map was classified as natural forest in the LCDB.
- 90% of the total forest cover identified from the MOF map matched with the forest-cover types in the LCDB.

Comparison of the LCDB with the Forest Class maps indicated that:

- 79% of the natural forest area identified from the LCDB was identified as natural forest in Forest Class maps (137,900 ha of 173,700 ha).
- 87% of the natural forest area identified from the Forest Class maps was also classified as natural forest in the LCDB (137,900 ha of 159,400 ha).

In view of the age of the Forest Class maps, agreement with the LCDB was surprisingly high. This indicates that the area of natural forest in the Taupo district has remained fairly constant over the last 20 years.

From Fig 3(a) the unmatched area of planted forest represents 20% of the area of planted forest derived from the LCDB and MOF maps. From Fig 3(b) the unmatched area represents 25% of the total area of natural forest. The unmatched areas would provide a useful starting-point for more accurate determination of forest type and extent, and could form the basis for a stratified random sampling approach.

Possible reasons for unmatched classifications include:

- Errors in the original mapping due to inaccurate machinery, poor registration, or errors in classification.
- Errors in satellite image classification due to difficulties in interpretation of spectral signatures or incorrectly determined land-cover type, e.g. very young planted forests.
- Changes in land cover, e.g. clearfelling.
- Use of different criteria in determination of land-cover types. Areas of regenerating natural bush could be identified from the LCDB as natural forest, but might not appear as such in the MOF map. They would not be represented in the Forest Class maps.
- Effects of working at different scales. Much of the MOF map was produced at 1:250,000 and the LCDB data at 1:25,000. This would cause differences to occur along boundaries (visible in Fig. 2) and as a result of cartographic generalisation.

For further validation of satellite image classification, it will be necessary to identify areas where the resolution of difference is likely to be most important. Alternative sources of information or methods of data capture will be needed, e.g. local knowledge, aerial videography/photography. Costs and demands associated with these are likely to determine the amount of additional data that can be obtained. The stratification approach suggested above should lead to more cost-effective validation than random sampling would achieve.

There is scope for further classification within the broad land-cover types adopted by DOSLI. From a plantation forestry perspective, the next step is to reclassify planted areas by species and age class. MOF and Landcare have already completed work in this area and have determined that *Pinus radiata* and Douglas fir (*Pseudotsuga menziesii*) have distinctive spectral signatures which can be readily classifed (White *et al.*, 1992). New Zealand

3 *TerraSoft, from Digital Resource Systems (now Essential Planning Systems, B.C., Canada)*

has excellent records of forest inventory and stand history which provide reference data for modelling and verification of age-class distribution. Further classification within natural forests will also be of value, allowing, for example, an opportunity for the investigation of relationships between spectral band combinations and the classifications used in Forest Class mapping.

CONCLUSIONS

The advent of land-cover mapping from satellite imagery at a national level heralds a new era in land information systems, enabling maps of large areas to be kept up-to-date. Although there is some loss of spatial resolution, compared to map production from aerial photography, the LCDB pilot scheme has shown that satellite imagery can be interpreted at levels of accuracy considered acceptable for a large proportion of land management purposes. Furthermore, data provided in digital format are more flexible for use in analysis and interpretation than with traditional hardcopy mapping. The use of automated image processing techniques for classification in the LCDB pilot scheme proved to be unsuccessful, but the potential that image processing offers for change detection introduces a new and significant dimension to land-cover and land-use monitoring programmes. The addition of this temporal dimension to land information sytems will highlight the need to develop models that enable time to be incorporated into spatial databases. This development will enable better analysis of the dynamic nature of our world, quantifying the changes that occur naturally and those imposed upon it by mankind.

The forestry issues addressed in this study represent only a small part of the potential that remote sensing offers to forestry. The project has brought several organisations together and the cooperative approach should enable individual agencies to achieve better results than they could have obtained independently. Reference to existing records should help to optimise the validation of satellite image classification, and provides acknowledgement of the valuable work already accomplished in forest inventory and map production.

ACKNOWLEDGEMENTS

DOSLI and MOF provided digital data and supporting documents. Two unpublished reports in particular, *A proposal for a New Zealand Land Cover Database* by N.P. Ching (1992) and *Land Cover Database Pilot Project Report* by T. Farrier (1993) were invaluable in the preparation of this paper. The assistance of Andrew Wilson and Paul Millin is gratefully acknowledged.

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APPENDIX I

Reference

Classified

	Urban	Q&D	Rec	Past	Hort	PFor	NGras	Scrub	NFor	BGrnd	InWet	CoSnd	Total
Urban	17	0	2	0	0	0	0	1	0	0	0	0	20
Q&D	0	3	0	0	0	0	0	0	0	0	0	0	3
Rec	0	0	7	1	0	0	0	0	0	0	0	0	8
Past	1	0	0	67	1	3	0	3	0	0	0	0	75
Hort	0	0	0	2	10	0	0	0	0	0	0	0	12
PFor	0	0	0	0	0	71	0	2	2	0	0	0	75
NGras	0	0	0	0	0	0	26	2	0	1	0	0	29
Scrub	0	0	0	2	0	1	1	66	5	0	0	0	75
NFor	0	0	0	2	0	2	2	2	67	0	0	0	75
BGrnd	0	0	0	0	0	0	3	0	0	23	0	0	26
InWet	0	0	0	0	0	0	0	0	0	0	5	0	5
CoSnd	0	0	0	0	0	0	0	0	0	0	0	2	2
Total	18	3	9	74	11	77	32	76	74	24	5	2	405

Error matrix for LCDB PIlot scheme

Reference values obtained from site visits and photo-interpretation.

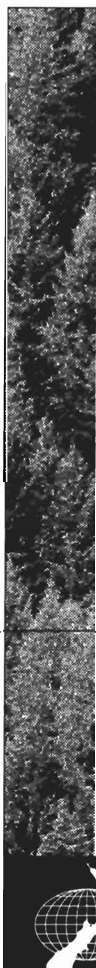
Classification values determined from image-interpretation, topographical maps, data collected from sites other than the reference sites, and other sources.

Sum of major diagonal is 364.

Overall accuracy is 364/405 = 90%.

Classification codes:

Urban	Urban areas
Q&D	Quarries/Dumps
Rec	Recreational areas
Past	Pasture (improved Grasslands & Croplands)
Hort	Orchard/Horticulture
PFor	Planted forest
NGras	Natural Grasslands (Tussock)
Scrub	Scrublands
NFor	Natural Forests
BGrnd	Bare Ground
InWet	Inland Wetlands
CoSnd	Coastal Sands



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