IMAGE ANALYSIS TECHNIQUES FOR ASSESSING LANDSCAPE STRUCTURAL CHANGE: A CASE STUDY OF THE LOCKYER VALLEY CATCHMENT, QUEENSLAND

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Abstract

An understanding of the landscape dynamics has great implications for land management. Knowing the landscape structure, the nature and magnitude of its changes, and how it affects landscape processes are essential in the sound management of lands and their resources. To develop appropriate mapping and landscape structural change assessment techniques, a case study of the Lockyer Valley catchment in Queensland, Australia, was conducted. Adopting a post-classification change detection method, the study used Landsat MSS (1973) and TM (1997) imagery which were separately classified using spatial masking and supervised classification (employing a maximum likelihood classifier with prior probabilities). The land use/cover maps produced were then utilised as input to a GIS-based landscape pattern calculation software to generate landscape structure indices. The study has yielded information about the degenerating state of the landscape in the catchment. The woody vegetation areas have become more fragmented, mainly due to conversion to pasture: they are characterised by the proliferation of small, less connected vegetation patches. This study highlighted the valuable use of remote sensing and GIS in mapping and analysis of landscape change. The critical issues identified include the difference in sensor spatial resolution and the shortcomings in calculating other spatial processes in land transformation.

1. Introduction

Human land use can significantly alter the ecology of a catchment. Improper land use practices can adversely affect many natural processes that lead to soil erosion, land degradation, habitat destruction, and water pollution. In particular, studies have shown that the proportion of different land uses within a catchment is directly related to variability in riverine water quality (*e.g.* Hunsaker and Levine, 1995; DelRegno and Atkinson, 1988). Soil erosion, soil salinity, water pollution and flooding are also often associated with inappropriate agricultural, industrial and urban land use practices.

In recent years, the relatively new field of landscape ecology has added a new dimension to land management. There is a growing recognition of the importance of the "landscape perspective"– the need to consider larger spatial and temporal scales than have traditionally been considered in policies and guidelines for managing state lands (Haines-Young *et al.*, 1993). Results from landscape ecological studies suggest that a broad-scale perspective incorporating spatial relationships is a necessary part of land-use planning (Turner, 1989). In particular, resource managers require spatial and temporal information to make decisions about landscape patch size, the dispersal or aggregation of activities, edge densities, and connectivity in the landscape (Franklin, 1994).

The ability to quantify landscape structure is prerequisite to the study of landscape function and change (McGarigal and Marks, 1994). Conversely, the quantification of landscape structure firstly requires delineation or mapping. Thus, mapping is an essential task for any landscape structural analysis. Although mapping and quantifying patterns of landscape change is not new, only few studies are reported in the literature (see for example, Skinner, 1995; Simpson, *et al.*, 1994; Turner and Ruscher, 1988). Studies are even scarce for mapping and assessing landscape change at a catchment scale. This gap needs to be addressed because catchment scale and hydrological fluxes have scale components which are strategic to an understanding of the functioning of the landscape (Farina, 1998, p. 48).

The objectives of this study are as follows:

1) to develop appropriate mapping and landscape structural change assessment techniques, including the identification of related problems, issues and opportunities; and

2) to evaluate the changes in the landscape structure of a catchment so as to gain insights on the nature and magnitude of these changes.

It is a part of a broader study focusing on the spatio-temporal assessment of landscape change and environmental indicators in a catchment in Queensland, Australia.

2. Landscape Structure and its Measurement

2.1. Landscape Structure and its Significance

A landscape is defined as a heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar form throughout (Forman and Godron, 1986). It is composed typically of several types of landscape elements (patches). Patches represent relatively discrete areas (spatial) of relatively homogeneous environmental conditions. The size of a landscape varies, depending on what constitutes a mosaic of habitat or resource patches meaningful to a particular organism (McGarigal and Marks, 1994). Generally, however, a landscape is accepted as a broad portion of a territory (Farina, 1998, p. 2). Forman and Godron (1986) suggested a lower limit for landscapes to be a “few kilometers in diameter”.

Landscape ecology is the study of the structure, function, and change in a landscape (Forman and Godron, 1986). Landscape structure refers to the spatial relationships among the distinctive ecosystems or “elements” present — more specifically, the distribution of energy, materials, and species in relation to sizes, shapes, numbers, kinds, and configurations of the ecosystems. On the other hand, landscape function deals with the interactions among the spatial elements, that is, the flows of energy, materials, and species among the component ecosystems. Lastly, landscape change focuses on the alteration in the structure and function of the ecological mosaic over time. This particular study concentrates on landscape structure and its change.

Landscape structure could be described by its composition and configuration. Landscape composition refers to features associated with the presence and amount of each patch type within the landscape, but without being spatially explicit (McGarigal and Marks, 1994). Typical measures of landscape composition include the proportion of the landscape in each patch type, patch richness, patch evenness, and patch diversity. On the other hand, landscape configuration (sometimes referred to as landscape pattern) refers to the physical distribution or spatial character of patches within the landscape (McGarigal and Marks, 1994). It could be quantified using statistics based on shape, nearest neighbour, contagion, and interspersion.

Landscape structure is a result of the complex interactions between physical, biological, economic, political and social driving forces. Most landscapes have been influenced by human land use, and the resulting landscape mosaic is a mixture of natural and human-managed patches that vary in size, shape, and arrangement (Turner, 1989). Landscapes differ structurally in the distribution of species, energy and materials, and therefore differ functionally in the flows of species, energy and materials among the elements (Forman and Godron, 1986).

The importance of landscape structure to resource and environmental planning has increased as studies continue to unveil vital spatial relationships that exist between various ecosystem components. Knight (1987) cited some of the studies that highlighted the significance of vegetation mosaics in fire spread, streamflow, and wildlife. He noted that more efficient resource utilisation and conservation could result when the importance and dynamics of the mosaic are understood as well as the dynamics of the patches.

Emerging practical applications of landscape ecological principles to land management can be found in the literature. For example, Fedorowick (1993) developed a landscape restoration framework in deriving design alternatives that can benefit both agriculture and wildlife in a fragmented landscape in Canada. Realising that an increased interconnected system of patches and corridors could benefit wildlife and agricultural production (Hobbs and Saunders, 1991), his design focused on adding patches and corridors, considering their number, location, and connectivity. Similarly, Apan (1996) formulated tropical forest rehabilitation strategies based on the size, shape, connectivity and the nature of bareland patches.

2.2. Landscape Metrics

A number of landscape metrics (or indices) that describe the landscape configuration and composition can be formulated either in terms of the individual patches or of the whole landscape. The most commonly used metrics can be grouped as follows (McGarigal and Marks, 1994):

- area metrics;
- patch density, patch size and variability metrics;
- edge metrics;
- shape metrics;
- core area metrics;

- nearest-neighbour metrics;
- diversity metrics; and
- contagion and interspersion metrics.

The size of a patch is one of the obvious, but yet an important characteristic of the landscape. Forman and Godron (1986) offer substantive discussions of the effects of patch size on energy and nutrients, and on species diversity. When designing nature reserves, for example, they noted that area is the factor usually given prime importance. While the discussion of the effect of patch area on community structure has been extensive (and the message from such studies is often complex), the implication is that larger patches generally hold a greater number of species than smaller patches (Lavers and Haines-Young, 1993). The smaller the fragmented blocks the more the density of populations decreases and the risk of extinction grows (Farina, 1998). Brokaw and Scheiner (1989) have provided data which indicate that differences in gap sizes may have produced variation in species composition.

Shape is also an important characteristic of a landscape patch. Its relevance is often related to “edge effect”: the presence of different species composition and abundance at the edge of the patch compared to its interior. A circular patch has a higher interior-to-edge ratio than an elongated patch of the same area. Patch shape and orientation are critical in the dispersal of animals and plants across a landscape (Forman and Godron, 1986). Whitmore (1975), as cited by Forman and Godron (1986), remarked that plant species composition and community structure varied according to the shape of open gaps in Malaysian tropical rain forest.

Landscape connectivity is a measure of how spatially contiguous a landscape matrix is. It is important for many ecological processes. Connectivity can exert strong influences on ecological processes, such as the movement and dispersal of organisms, the use of resources by animals, gene flow, and the spread of disturbance (Pearson, 1994). For instance, the increase in woodland connectedness after land abandonment has favoured the diffusion of wild boar in most of the mountain landscapes of Europe (Farina, 1998, p. 58). In addition, modifications of habitat connectivity can have strong influences on species abundance (Turner, 1989).

3. Research Methods

3.1 Study Area

The study area covers the Lockyer Valley Catchment, South East Queensland, Australia, with a total area of about 300,800 hectares (figure 1). The Gatton shire, the catchment’s biggest and most central, is located approximately 90 km west of Brisbane, the capital city of Queensland.

The area’s topography varies from flat (mainly creek flats located at the centre to north-east side of the catchment) to ruggedly steep (mainly mountains and hills in the south-western and northern parts). Slope ranges from 0 to 58 degrees with an average slope of 29 degrees. Elevation ranges from 27 to 1,106 meters above mean sea level. In terms of bedrock geology, about 55% of the area is sandstone, while some 25% of the area is basalt. In alluvial plains, soils are generally of the deep black cracking-clay soils and dark brown clay loams. Other areas have generally shallow, stony, low in fertility, or sandy soils.

With a local population of about 22,000 (EPA, 1999), the Lockyer Valley encompasses some of the richest farming land in Australia and supports one of the Queensland's most important centres of diversified agriculture. Known as the "Breadbasket of Queensland", the activities in the catchment are mainly centred on farming and cattle grazing, and timber production. Pasture dominates (47%) the land use/cover types, followed by woody vegetation (41%) and crops (11%).

In a land cover change study of south-east Queensland by the Statewide Land Cover and Trees Study (SLATS) (DNR, 1999), the Brisbane River catchment (where the Lockyer Valley is a sub-catchment) had an average vegetation clearing of 1,960 hectares per year for the period 1988-1997. The six different sub-catchments comprising the Lockyer Valley catchment had a rate of vegetation clearing from 4.2 to 197.5 hectares per year. In all sub-catchments of the study area, the majority of woody vegetation areas is cleared for pasture (about 78% to 100% of all clearings). In the Lockyer Creek sub-catchment, about 291 and 71 hectares of vegetation were cleared for settlement and infrastructures, respectively.

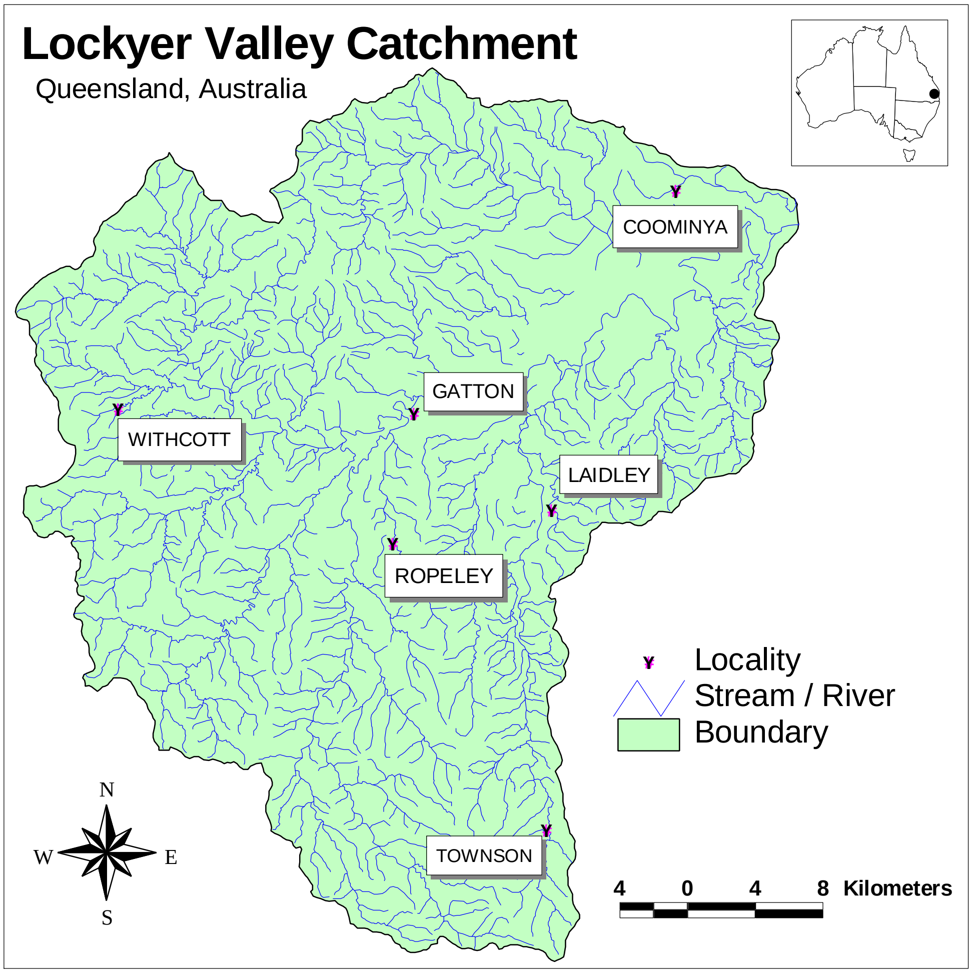


Figure 1. Location map of the study area.

3.2. Data Acquisition and Image Processing

The goal of digital image processing for this study was to produce a reliable land use/cover map for each of the two Landsat images (1973 and 1997) acquired for the study area (figures 2 and 3). The GIS provided the environment where these raster images and other thematic maps were pre-processed, displayed and analysed. Both major tasks employed ARC/INFO Revision 7 and ArcView 3.1 GIS software (ESRI, 1996; 1997). The GRID module of ARC/INFO, running from a remote server of the Queensland Parallel Supercomputer Facility, was employed specifically for digital image processing. The flowchart of the techniques employed in mapping and analysis of landscape structural change is given in figure 4. The digital image processing techniques for the post-classification landscape structural change analysis is illustrated in figure 5.

For conventional land cover change analysis, *i.e.* not necessarily for landscape structural change analysis, the methods could be grouped into two broad categories: pre-classification spectral change detection methods and post-classification change detection methods (refer to Yuan, *et al.*, 1998). In post-classification change detection, two images from different dates are independently classified and labelled. The area of change is then determined through the direct comparison of the classification results. This method is favourable if the images involved in change detection were acquired at different times of the year or by different sensors. Because the study uses two different sensors, the post-classification change detection method was deemed suitable and implemented here.

A 75 km x 66 km subset was used from a Landsat 5 Thematic Mapper (TM) digital data, taken on September 1997. The same image extent was utilised for the August 1973 Landsat 1 Multispectral Scanner (MSS) data. The TM image was acquired as geocoded format (with a reported maximum root mean square error of 20 meters) in a UTM projection based on the ADG 84 datum. On the other hand, the MSS data was acquired as raw ungeocoded data.

For the 1997 TM image, all the visible and infrared bands, except the thermal infrared, were included in the supervised image classification. In addition, a Normalised Differenced Vegetation Index (NDVI) image was used to help quantify the relative vegetation greenness and biomass (*e.g.* Hatfield *et al.*, 1985). NDVI is also known to reduce the topographic shadow effect in high relief areas. For the 1973 MSS image, all the four bands were used, including an NDVI image derived from the MSS data.

After all the necessary radiometric and geometric corrections were implemented (following similar procedures used by Apan, 1997), contiguous blocks of training areas for each of the land use/cover classes under study were selected. These samples were based on *a priori* knowledge, and information from ancillary maps and field data gathering. Signature evaluation was done using ellipses and dendrograms to examine the spectral properties of individual training sample class and its separability over others. In view of its desirable characteristics (*e.g.* Richards, 1993), the maximum likelihood algorithm was employed, with classes set to different *a priori* probability based on expected total area. This *a priori* information is based from the 1991 land cover and foliage projective cover datasets from SLATS, and from the 1974 topographic maps.

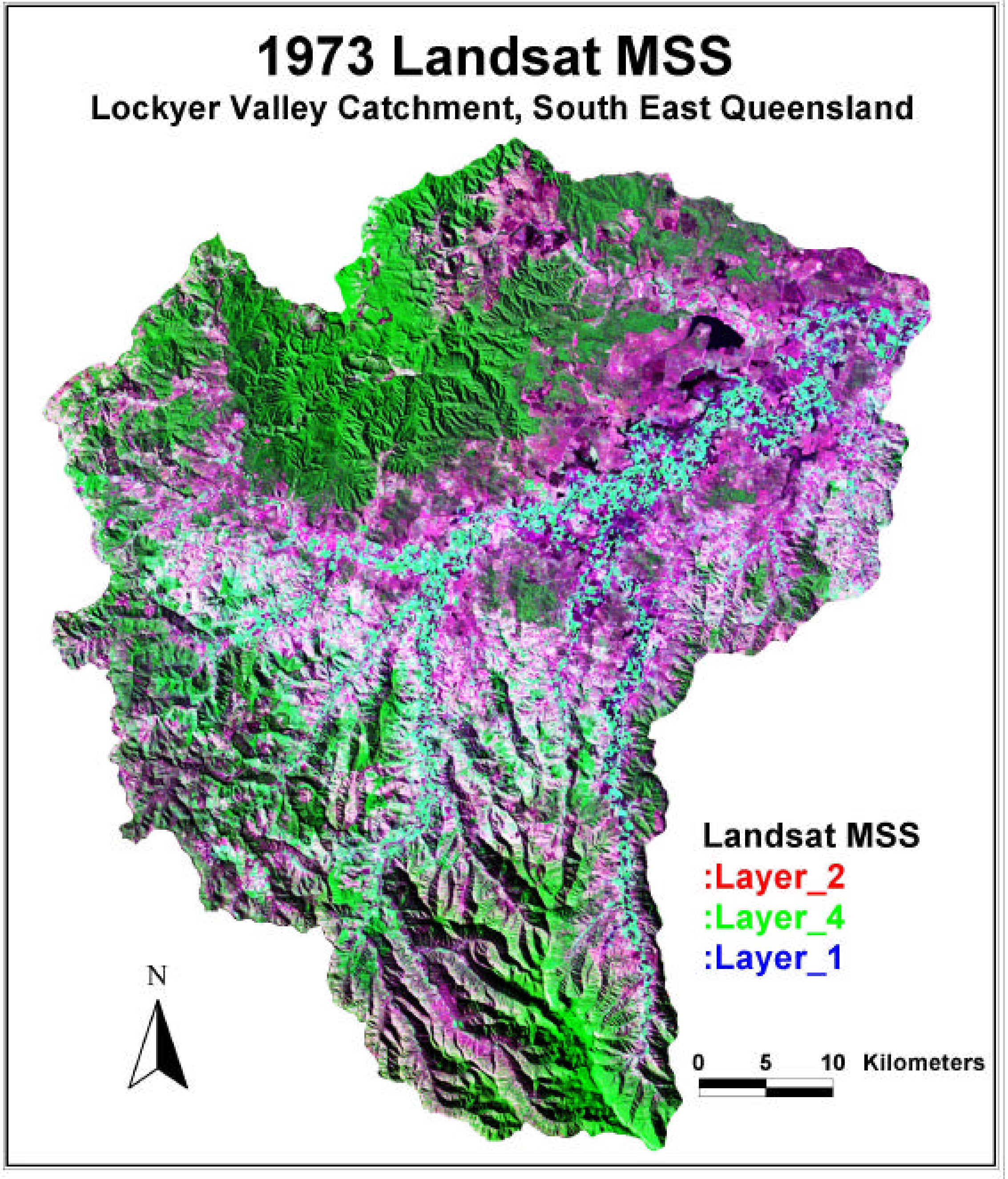


Figure 2. Landsat MSS (1973) of the study area.

Because spectral confusions were observed in some classes of the classified image from a diagnostic run, masking out of concerned land use/cover classes (*i.e.* water bodies, settlement, cropping area, and topographic shadows) was implemented. The idea was to exclude the known area (based from other reliable sources) from automated processing, and then to "paste" it later.

Previous studies have indicated that sensor spatial resolution (the determinant of scale) has effects on landscape structure parameters (see for example, Benzon and Mackenzie, 1995; Moody and Woodcock, 1995). In response to this, the study implemented the following measures (see also Barnsley, *et al.*, 1997):

- adopt a broader level of classification;
- perform a region-based generalisation procedure for the classified Landsat TM image (*i.e.* remove all same-class contiguous pixels that are less than 2 pixels); and
- resample both images to 50 m, bringing the TM image to a coarser spatial resolution (*i.e.* not "refining" the 80-m MSS data).

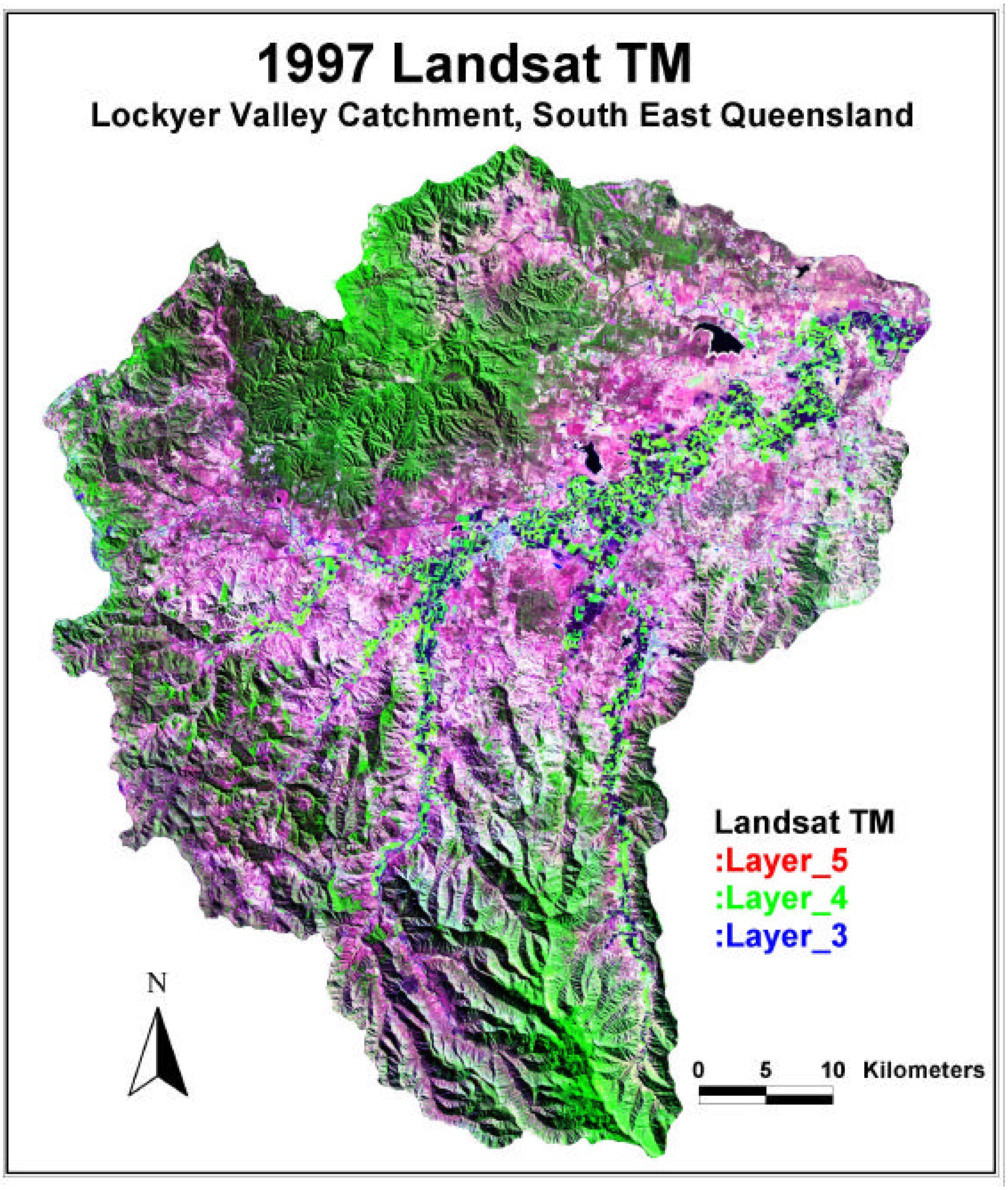


Figure 3. Landsat TM (1997) of the study area.

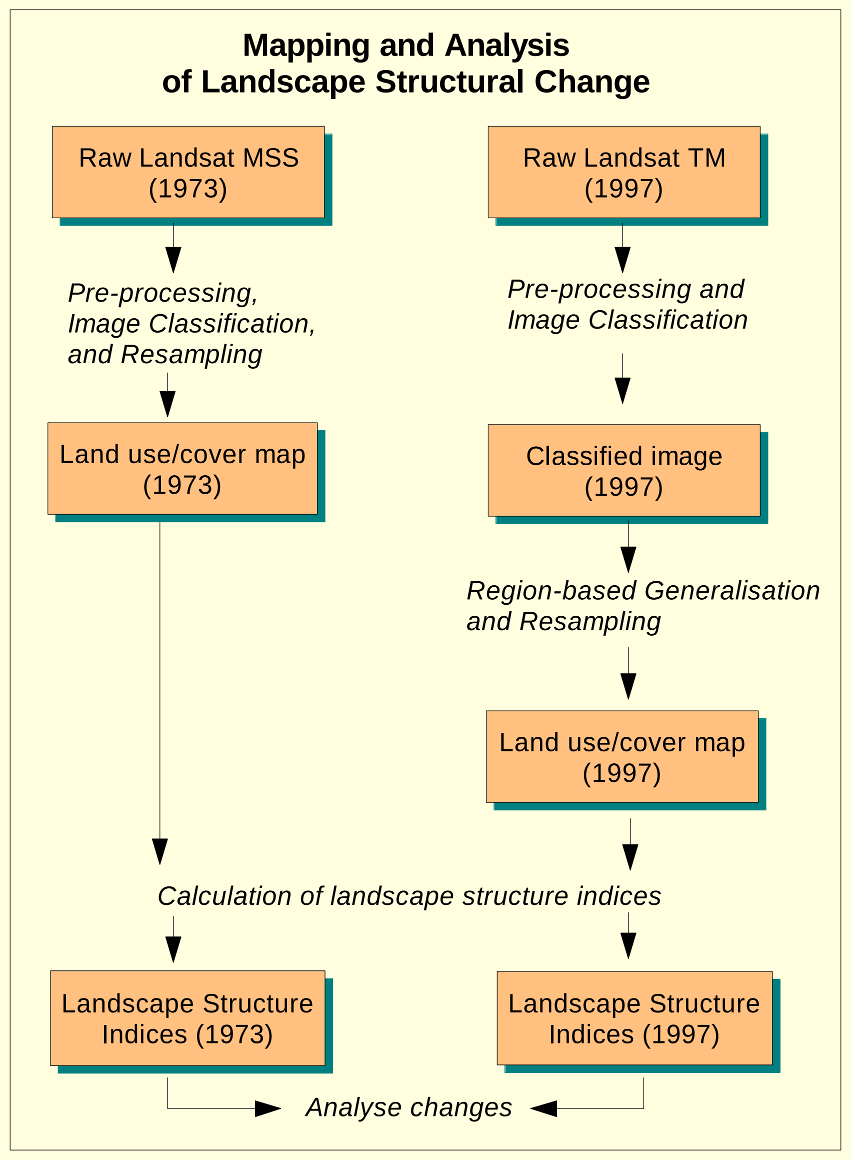


Figure. 4. Major steps in mapping and analysis of landscape structural change.

The accuracy of the result is considered fit for the goal of this study, thus no formal classification accuracy assessment (*e.g.* the use of error matrix) was implemented, except for some visual inspections. The two main reasons are as follows: a) due to masking out of some classes, the classes subjected to classification (*i.e.* vegetation and pasture) are those with very high spectral separability; and b) the level of classification used is relatively broad, *i.e.* not in detailed vegetation or pasture classes.

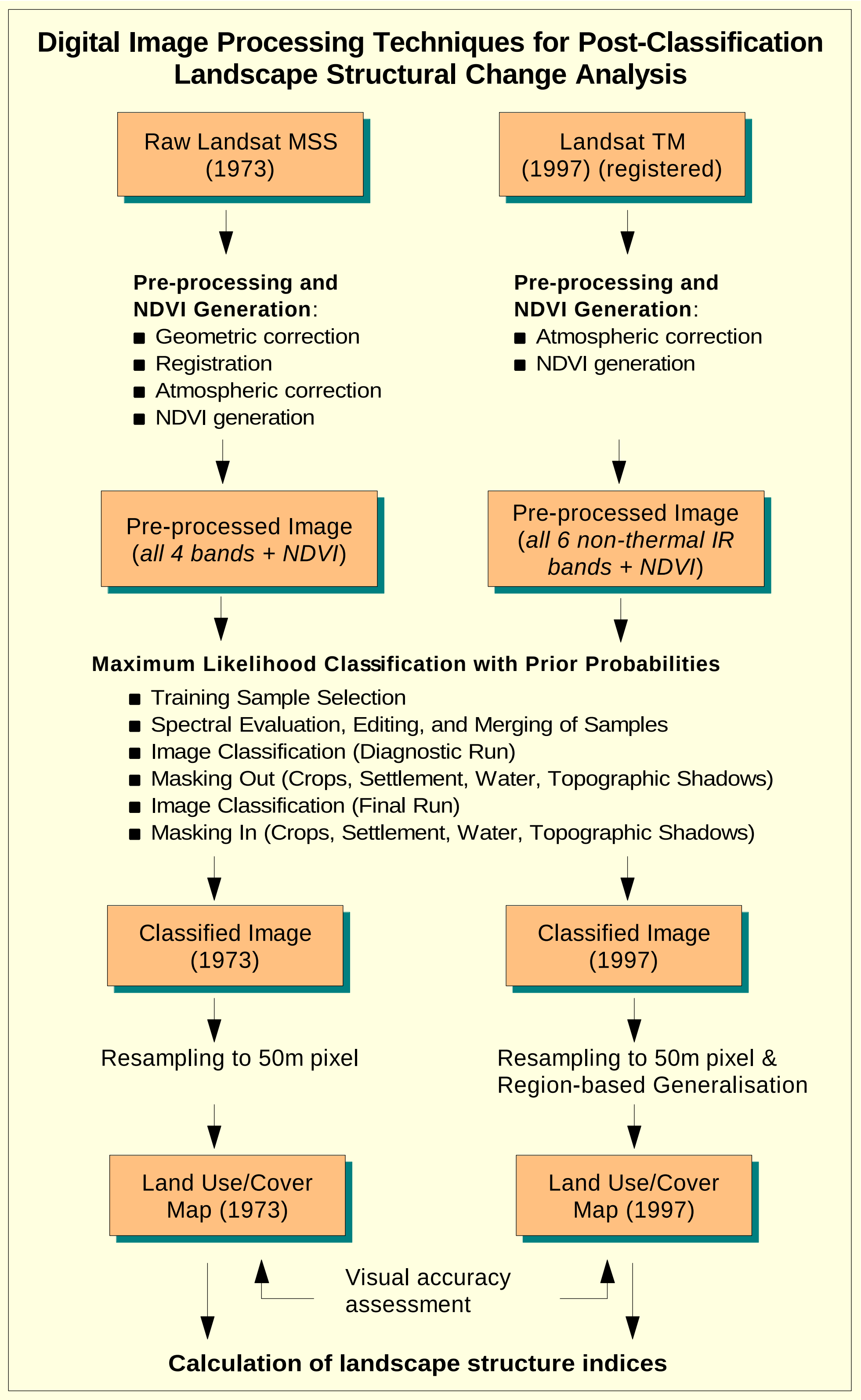


Figure 5. Digital image processing techniques for post-classification landscape structural change analysis.

3.3. Landscape Metrics Calculation

In this study, quantifying the landscape structure and its change over time involved the use of statistics (also called "metrics" or "indices") that describe the landscape configuration and composition. The program Patch Analyst (Grid) 1.1 (Rempel, *et al.* 1999), an extension to the ArcView GIS system, was used in generating landscape indices. The extension includes patch analysis functions developed using Avenue code, and an interface to the FRAGSTATS spatial pattern analysis program developed by McGarigal and Marks (1994). The program offers a comprehensive choice of landscape metrics at the patch, class, and landscape levels. This study mainly focused on the woody vegetation class that included one or more metrics from the broad groups mentioned above.

A "cross tabulation" overlay in GIS was performed to create a thematic map depicting all the possible combinations of change (*e.g.* pasture to agricultural crops, woody vegetation to settlement, etc.) between the 1973 and 1997 images. To further understand the nature of landscape change, all changes in the catchment involving woody vegetation (*i.e.* from woody vegetation to pasture, agricultural crops, settlement, or water) were mapped and analysed.

4. Results

4.1. Image Processing

As expected, visual/manual image interpretation of contrast enhanced Landsat TM and MSS images (*e.g.* TM 3, 4, and 5, displayed in Blue, Green, and Red, respectively) allowed the easy differentiation between the vegetated and non-vegetated areas. In general, dry bare soil of pasture areas have high brightness values in the visible bands and low brightness values in the infrared band, while the reverse is true for green healthy vegetation. Water bodies could be adequately discriminated by visual inspection, but not by its black to bluish colour in TM 3, 4, and 5, but by pattern and associated location. Most topographic shadows, being black, can sometimes be confused with deep water. In addition, "black soil" areas (typical of alluvial flats in the Lockyer Valley) and wet soil have relatively low reflectance in most bands, thus they become sources of confusions for water bodies and topographic shadows.

Statistical analyses of spectral responses from training samples, as well as ellipse and dendrogram plots, show the close or overlapping values of these "dark pixel" features (water, black soil, wet soil, and topographic shadows). In addition, some sunlit vegetation areas have close or overlapping values with certain agricultural (*e.g.* vegetable) crops. Confusions can be also inferred between a few patches of bare soil and residential areas. In contrast, most vegetation and non-vegetation areas (bare soil, water) are spectrally distinct. Although efforts have been made to re-define training samples or merge related classes, the spectral evaluation of the final samples has indicated some potential classification problems.

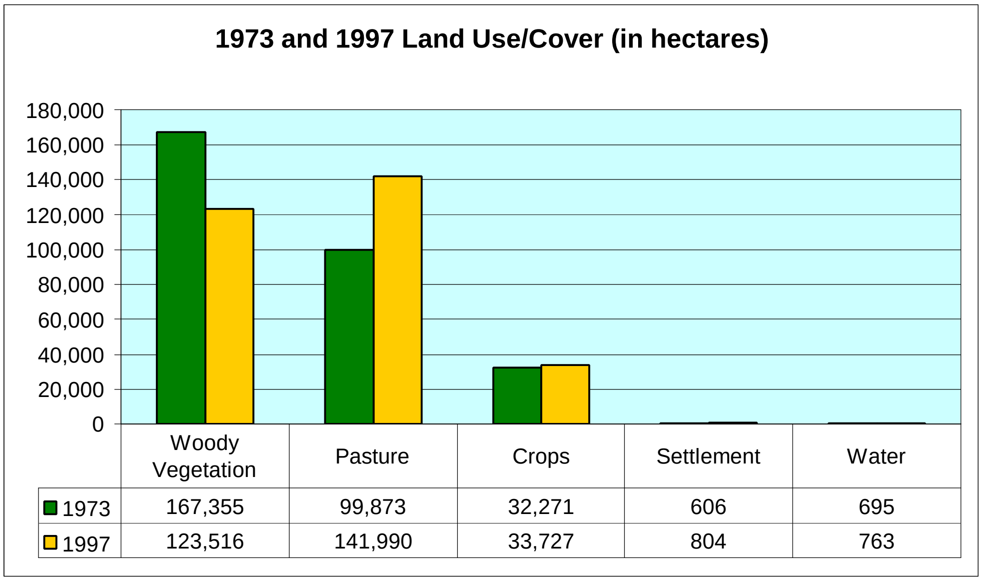
The results of the first run of the maximum likelihood classification confirm the above findings of the training sample statistical evaluation. Many areas were misclassified, following the patterns of confusions previously described. After masking out of water bodies, agricultural crops, settlement and topographic shadows was implemented, only woody vegetation and pasture were left to be classified. The final classification of the area, followed by masking in of areas previously excluded, have yielded five classes: *woody vegetation*, *pasture*, *crops*, *settlement*, and *water*. These class definitions were adapted after modification from the SLATS project (*e.g.* DNR, 1999).

4.2. Changes in Area, Patch Density, Patch Size, and Patch Shape

The area of woody vegetation in the catchment has significantly decreased within the 24-year study period (figure 6 and table 1). Vegetation clearing totalled to about 44,110 hectares, or about 1,838 hectares per year. In 1973, the woody vegetation was about 56% of the total catchment and the most dominant landscape feature. However in 1997, this was reduced to 41%, making it only second to pasture when it comes to the relative area/size of classes. The results show that woody vegetation were mainly cleared for pasture, comprising about 98% of the total cleared area (Table 2). A much smaller percentage of clearings also occurred to pave way for agricultural crops, water, and settlement.

The data on patch density, patch size, and largest patch index indicated that the catchment has undergone considerable fragmentation of vegetation (table 1). The number of patches has substantially increased, suggesting the breaking up of vegetation areas into smaller parcels (from 4,964 to 8,000 patches). This view that extensive land transformation has occurred in the catchment is further supported by the mean patch size, patch size coefficient of variation, and the large patch index. For instance, the mean patch size was reduced to about half (33.71 to 15.44 hectares), while the largest patch was reduced from 47% to 20% of the landscape.

Regarding patch shape, the mean shape index values of vegetation class for the 1973 and 1997 catchment are greater than 1, indicating that the average vegetation patch shape in all landscapes in non-square. The 1997 patches (more fragmented) are slightly less irregular in shape that the 1973 patches (less fragmented). This difference is negligible in mean patch fractal value — the two images showed no difference.



	Woody Vegetation	Pasture	Crops	Settlement	Water
🟩 1973	167,355	99,873	32,271	606	695
🟨 1997	123,516	141,990	33,727	804	763

Figure 6. Land use/cover (1973 and 1997)

Table 1. Results of landscape structural change calculations for woody vegetation

Indices	**Year**	
	1973	1997
CLASS LEVEL: Vegetation		
Class Area (ha)	167,355	123,516
Percent of Landscape (%)	55.64	41.06
Number of Patches	4,964	8,000
Patch Density (# / 100 ha)	1.65	2.66
Mean Patch Size (ha)	33.71	15.44
Patch Size CV[a] (%)	5,980.02	4,711.45
Largest Patch Index (%)[b]	47.20	20.36
Mean Shape Index[c]	1.30	1.33
Mean Patch Fractal[d]	1.04	1.04
Mean Nearest Neighbour Distance (m)[e]	89.12	99.01
Nearest Neighbour CV (%)	73.19	98.54
Mean Proximity Index[f]	84,214	21,446
Interspersion/Juxtaposition (%)[g]	19.90	12.06

[a] coefficient of variation; it is equal to 0 when there is no variability in patch size

[b] the percentage of total landscape area comprised by the largest patch

[c] the average perimeter-to-area ratio; it is equal to 1 when all patches of the corresponding patch type are square; it increases without limit as the patch shapes become more irregular

[d] the average fractal dimension; it approaches 1 for shapes with very simple perimeters such as circles or squares; it approaches 2 for shapes with highly convoluted, plane-filling perimeters

[e] the average edge-to-edge distance from a patch to the nearest neighboring patch of the same type

[f] measures the degree of patch isolation and fragmentation; it is equal to 0 if all patches of the corresponding patch type have no neighbours of the same type within the specified search radius (100 m in this study); it increases as patches become less isolated and the patch type becomes less fragmented in distribution

[g] measures the extent to which patch types are interspersed; it approaches 0 when the corresponding patch type is adjacent to only 1 other patch type and the number of patch types increases; it is equal to 100 when the corresponding patch type is equally adjacent to all other patch types (*i.e.* maximally interspersed and juxtaposed to other patches)

Table 2. Results of thematic change calculations (1973 to 1997) focusing on woody vegetation change

Thematic Change (1973 to 1997)	**Area**	**%**
Woody Vegetation to Pasture	43,413	98.42
Woody Vegetation to Crop	604	1.37
Woody Vegetation to Settlement	35	0.08
Woody Vegetation to Water	57	0.13
TOTAL	**44,110**	**100**

3.3. Changes in the Nearest-Neighbour Metrics and Interspersion

The average nearest-neighbour distance values for the 1973 and 1997 images has decreased from 89 m to 99 m. These values indicate decreasing inter-patch connectivity due to fragmentation. The 1997 patches are becoming more isolated. The mean proximity index values support this view: there is a substantial decrease from 84,214 to 21,446, indicating that the vegetation patches have become more isolated and more fragmented in distribution.

The 1973 image has higher interspersion and juxtaposition indices than the 1997 image (19.90 as against 12.06) indicating that the vegetation patches in the former are well interspersed or equitably distributed among patch types (*i.e.* equally adjacent to each other). The 1997 landscape indicates more disproportionate distribution of vegetation patch adjacencies.

5. Discussions

5.1. Mapping and Landscape Metrics Calculations

Satellite imagery provided the land use/cover map in the landscape scale needed for the study. The different land use/cover classes were adequately mapped with the use of spatial masking and supervised classification using the maximum likelihood algorithm with prior probabilities. The adequate delineation of vegetated and non-vegetated areas is expected because the capability of remotely sensed data to delineate vegetated and bare areas is well-established. The contrasting reflectance properties of bare areas and vegetation in the visible and infrared bands ensured their easy differentiation. Vegetation can usually be classified apart from non-vegetation. Even using lower spatial resolution Landsat MSS data, these two general land cover categories should be spectrally separated (*e.g.* Singh, 1987).

The utility of remotely sensed data in extracting the above information is of great value to landscape mapping as the starting point of most landscape ecological studies is focused on vegetation patches. Vegetation affects many ecological processes. However, the accurate identification and delineation of woody/forested vegetation patches from other vegetation cover such as grasses, shrubs and agricultural crops, is quite difficult in some cases. The use of external data by spatial (not spectral) masking is seen as the best approach.

The problems associated with mapping landscape structure and its changes using satellite imagery are also those typical in most land use/cover mapping employing this technology. These include the following:

- the close or overlapping spectral response of some surface features which can cause classification confusions;
- the presence of topographic shadows which could not be completely eradicated by techniques such as band ratioing;
- the availability of cloud-free image (this project is still waiting for a cloud free 1999 or 2000 image of the catchment); and

- the problems associated with difference in sensor systems, particularly the spatial resolution.

As previously mentioned, some measures were implemented to address the dissimilar sensor spatial resolutions (*i.e.* Landsat MSS *vs*. TM) used in this study, including region-based generalisation, resampling, and adopting a broader level of classification. While these techniques could help, in theory, to make the two sensors yield comparable landscape metrics, there is a need to develop techniques that could quantitatively verify the effects of one or all of those measures. In a landscape structural change assessment involving sensors of different spatial resolution, eliminating or reducing their differences at the desired level is essential. These authors are currently conducting a study in this regard.

While the concept of landscape fragmentation (in the narrower sense refers to the breaking up of habitat or land type into smaller parcels) is often referred to in the literature, there are other spatial processes in land transformation that need to be mapped: perforation, dissection, shrinkage and attrition (*e.g.* Forman, 1997, pp. 405-409). A vegetation patch may have shrunk and became perforated, but did not become fragmented. Yet, the impact of shrinkage and perforation on the landscape processes could be more important. In the study area, visual examination of the satellite imagery unveils that there are many riparian vegetation patches that decreased in size, disappeared, dissected, or became perforated. For instance, a road network (Gatton by-pass) constructed in the late 1970s dissected or subdivided some vegetation patches into sections.

Although the Patch Analyst (Grid) and FRAGSTATS software used in this study provided a wide range of indices relevant to landscape structural change analysis, these software are deficient in quantifying other spatial processes in land transformation. For example, no metrics are available that will indicate on how much of an original patch has decreased in size, become perforated, or totally disappeared. The two software has provisions for calculating metrics on individual patch level, but lacks mechanism to track down changes to individual patches. With only two or three patches, these could be easily calculated manually. However, because many landscapes cover a large area of numerous irregularly shaped patches, the development of automated techniques is preferable.

5.2. Landscape Structure and its Changes

The different landscape metrics, such as area, patch density, mean patch size, largest patch index, patch shape, interspersion, nearest-neighbour distance and mean proximity index, reveal that the structure of the riparian landscape in this study has significantly changed. While the 1973 riparian landscape has already shown signs of high human-induced fragmentation, the 1997 landscape has even become more fragmented. Within the 24-year study period, some 44,110 hectares of woody vegetation were converted to either pasture, agricultural cropland, water, or settlement, which caused the proliferation of small, less connected vegetation patches. Moreover, although not so dramatic, these results also indicate that fragmentation in the 1997 landscape caused a simplification in patch shapes compared to the geometrically complex patch shapes found in many natural landscapes.

Because of the two-date (1973 and 1997) satellite image used, only two-way landscape patterns could be observed, *e.g.* vegetation to pasture, crops to settlement, or vegetation to crops. While this information could be sufficient to some analysis, knowledge on multi-period mosaic sequence (*e.g.* vegetation to pasture to crops; vegetation to pasture to vegetation; or pasture to vegetation to crops to pasture, etc.) could be more important in developing spatially distributed landscape models. In the two-date period used in this study, the transformations in the landscapes could be mapped and quantified with relative ease. However, there might be some intervening land transformation that took place between this period which were not captured by the two-date change assessment.

6. Conclusions

While mapping land use/cover from satellite data is not a critical problem in landscape structural change assessment involving broad thematic classes, there is a need to address the issue of eliminating or reducing the differences in sensor spatial resolution of multi-date imagery. If any normalisation techniques are used to address this problem, quantitative indicators of their performances are necessary to help the interpretation and comparison of classified images. Moreover, while current software can provide a wide range of indices relevant to landscape structural change analysis, specialised computer programs that could quantify other spatial processes in land transformation (*e.g.* perforation, dissection, shrinkage and attrition) are needed to complement existing analytical capabilities.

The mapping and quantification of changes in the landscape structure of the Lockyer Valley catchment has yielded information about its degenerating state. Due to the significant decrease in vegetation areas, mainly due to conversion to pasture, the catchment's landscape has become more fragmented: they are characterised by the proliferation of small, less connected vegetation patches. To help mitigate the negative ecological effects of this condition, relevant landscape ecological principles should be included in catchment planning and management, particularly the need to enhance the landscape connectivity by revegetation in critical areas like the riparian zones. More importantly, vegetation clearing should be minimised, if not totally stopped, by appropriate legislation and information campaigns.

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References

APAN, A., 1996, Tropical landscape characterization and analysis for forest rehabilitation planning using satellite data and GIS. *Landscape and Urban Planning Journal*, **34**, 45-54.

APAN, A., 1997, Land Cover Mapping for Tropical Forest Rehabilitation Planning Using Remotely Sensed Data. *International Journal of Remote Sensing*, **18**, 1029-1049.

BARNSLEY, M. J., BARR, S.L., and TSANG, T., 1997, Scaling and generalisation in land cover mapping from satellite sensors. In *Scaling-up: From Cell to Landscape*, edited by P.R. Van Gardingen, G.M. Foody, and P.J. Curran (Cambridge: Cambridge University Press), pp. 173-199.

BENSON, B. J. and MACKENZIE, M.D., 1995, Effects of sensor resolution on landscape structure parameters. *Landscape Ecology*, **10**,113-120.

BROKAW, N.V.L. and SCHEINER, S.M., 1989, Species composition in gaps and structure of a tropical forest. *Ecology*, **70**, 538-541.

DELREGNO, K.J. and ATKINSON, S.F., 1988, Nonpoint pollution and watershed management: A remote sensing and geographic information systems (GIS) approach, *Lake Reservoir Management*, **4**, 17-25.

DNR, 1998, *1998-1999 Budget at a glance* (Queensland: Department of Natural Resources).

DNR, 1999, *Land Cover Change in South-East Queensland, 1988-1997* (Brisbane: Statewide Land Cover and Trees Study, Department of Natural Resources).

EPA (Environmental Protection Agency), 1999, *State of the Environment Queensland 1999* (Brisbane: Environmental Protection Agency).

ESRI (Environmental Systems Research Institute), 1996. *ARC/INFO Rev. 7.1* (Redlands, California: Environmental Systems Research Institute).

ESRI (Environmental Systems Research Institute), 1997. *ArcView GIS* (Redlands, California: Environmental Systems Research Institute).

FEDOROWICK, J.M., 1993, A landscape restoration framework for wildlife and agriculture in the rural landscape. *Landscape and Urban Planning*, **27**, 7-17.

FORMAN, R.T.T. and GODRON, M. 1986, *Landscape Ecology*. (New York: John Wiley & Sons).

FRANKLIN, J.F., 1994, Developing information essential to policy, planning and management decision-making: The promise of GIS. In *Remote Sensing and GIS in Ecosystem Management*, edited by V. Alaric Sample (Washington DC: Island Press), pp. 18-24.

HAINES-YOUNG, R., GREEN, D.R. and COUSINS, S. (eds), 1993, *Landscape Ecology and Geographic Information Systems* (London: Taylor and Francis).

HUNSAKER, C.T. and LEVINE, D.A., 1995, Hierarchical approaches to the study of water quality in rivers, *BioScience*, **45**, 193-203.

KNIGHT, D.H., 1987, Parasites, lightning, and vegetation mosaic in wilderness landscapes. In *Landscape Heterogeneity and Disturbance*, edited by M. G. Turner (New York: Springer-Verlag), pp. 59-83.

LAVERS, C.P. and HAINES-YOUNG, R., 1993, Equilibrium landscapes and their aftermath: spatial heterogeneity and the role of new technology. In *Landscape ecology and geographic information systems*, edited by R. Haines-Young, D.R. Green, and S. Cousins (London: Taylor and Francis), pp. 57-74.

MCGARIGAL, K. and MARKS, B.J., 1994, *FRAGSTATS: Spatial Pattern Analysis Program for Quantifying Landscape Structure (Vesion 2.0)* (Corvallis: Forest Science Department, Oregon State University).

MOODY, A. and WOODCOCK, C. E., 1995, The influence of scale and the spatial characteristics of landscapes on land cover-mapping using remote sensing. *Landscape Ecology*, **10**, 363-379.

PEARSON, S.M., 1994, Ecological perspective: Understanding the impacts of forest fragmentation. In *Remote Sensing and GIS in Ecosystem Management*, edited by V. Alaric Sample (Washington DC: Island Press), pp. 178-191.

REMPEL, R.S., CARR, A., and ELKIE, P., 1999, *Patch analyst and patch analyst (grid) function reference*. (Ontario: Centre for Northern Forest Ecosystem Research, Ontario Ministry of Natural Resources, Lakehead University, Thunder Bay).

RICHARDS, J. A., 1993, *Remote Sensing Digital Image Analysis: An Introduction*, 2nd ed. (Berlin: Springer-Verlag, Berlin).

SIMPSON, J. W., BOERNER, R.E.J., DEMERS, M.N., and BERNS, L.A., 1994, Forty-eight years of landscape change on two contiguous Ohio landscapes, *Landscape Ecology*, **9**, 261-270.

SINGH, A., 1987, Spectral separability of tropical forest cover classes. *International Journal of Remote Sensing*, **8**, 971-979.

SKINNER, C.N., 1995, Change in spatial characteristics of forest openings in the Klamath Mountains of Northwestern California. *Landscape Ecology*, **10**, 219-228.

TURNER, M.G., 1989, Landscape Ecology: The effect of patterns on process. *Annu. Rev. Ecol. Syst.*, **20**, 171-91.

TURNER, M.G. and RUSCHER, C.L., 1988, Changes in landscape patterns in Georgia, USA. *Landscape Ecology*, **1**, 241-251.

YUAN, D., ELVIDGE, C.D., and LUNETTA, R.S., 1998, Survey of Multispectral Methods for Land Cover Change Analysis. In *Remote Sensing Change Detection: Environmental Monitoring Methods and Applications*, edited by R.S. Lunetta and C.D. Elvidge (Michigan: Ann Arbor Press).