Mapping and Analysis of Changes in the Riparian Landscape Structure of the Lockyer Valley Catchment, Queensland, Australia

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Abstract

A case study of the Lockyer Valley catchment in Queensland, Australia, was conducted to develop appropriate mapping and assessment techniques to quantify the nature and magnitude of riparian landscape structural changes within a catchment. The study employed digital image processing techniques to produce land cover maps from the 1973 and 1997 Landsat imagery. Fixed and variable width buffering of streams were implemented using a geographic information system (GIS) to estimate the riparian zone and to subsequently calculate the landscape patterns using the Patch Analyst (Grid) program (a FRAGSTATS interface). The nature of vegetation clearing was characterised based on land tenure, slope and stream order. Using the Pearson chi-square test and Cramer’s V statistic, the relationships between the vegetation clearing and land tenure were further assessed. The results show the significant decrease in woody vegetation areas mainly due to conversion to pasture. Riparian vegetation corridors have become more fragmented, isolated and of much smaller patches. Land tenure was found to be significantly associated with the vegetation clearing, although the strength of association was weak. The large proportion of deforested riparian zones within steep slopes or first-order streams raises serious questions about the catchment health and the longer term potential for land degradation by upland clearing. This study highlights the use of satellite imagery and geographic information systems in mapping and analysis of landscape structural change, as well as the identification of key issues related to sensor spatial resolution, stream buffering widths, and the quantification of land transformation processes.

Keywords: riparian landscape; landscape structure; landscape change; remote sensing; GIS

1. Introduction

Riparian landscapes include land areas adjacent to a river or stream. They are unique environments because of their positions, structures and functions in the landscape. Riparian areas are important pathways for the flow of energy, matter and organisms through the landscape and act as ecotones between the terrestrial and aquatic zones and corridors across regions (Forman, 1997, p. 208; Malanson, 1993, p. 37). They are valuable natural resources that could serve a wide variety of productive, protective, and aesthetic functions (e.g. Tabacchi et al., 2000; Thoms and Sheldom, 2000; Forman, 1997, pp. 213-246).

River corridors are by far the most dynamic location in both natural and altered landscapes (Forman, 1997, p. 209). Anthropogenic activities, such as agriculture and livestock, mining, industry, transportation and communication, and urbanisation, have caused alteration or degradation of many riparian environments (e.g. Robertson and Rowling, 2000; Merritt et al., 2000; EPA 1999; Gurnell, 1997). If left unabated, the continuous misuse of these resources could bring further ecological problems and economic losses. Hence, there is a need to effectively manage these areas through restoration, rehabilitation, conservation or preservation programmes (Schiemer et al., 1999; Cals et al., 1998; Harper et al., 1999; Piegay and Landon, 1997).

The field of landscape ecology has added a new dimension to land management with 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 increasingly 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).

Riparian landscapes need to be mapped, quantified and assessed, to improve the understanding of the relationships between landscape elements and ecological processes (e.g. Basnyat et al., 1999). Knowing the riparian landscape structure and how it affects landscape processes will help in making informed decisions in planning and management of riparian areas (e.g. for revegetation of degraded areas, retention of vegetation, streambank stabilisation, and stock management). An understanding of landscape dynamics has tremendous implications for landscape management and reserve planning (Farina, 1998, p. 114).

Although several studies pertaining to changes in riparian conditions (e.g. vegetation, land use and channel change) have been conducted (e.g. Merritt et al., 2000; Gurnell, 1997; Gurnell et al., 1998; Beavis et al., 1999), very little has been done to quantitatively assess structural change in riparian landscapes. While there is nothing particularly new about using GIS and remote sensing for mapping and spatial analysis, its application for assessing riparian landscape structural change has rarely been exploited (e.g. Schuft et al., 1999, and see recent review of Herzog et al., 2001). Hence, the objective of this study was to develop appropriate mapping and assessment techniques to quantify the nature and magnitude of riparian landscape structural changes within a catchment.

2. Landscape Structure and Riparian Landscapes

A landscape is a mosaic where the mix of local ecosystems or land uses is repeated in similar form over a wide area (Forman, 1997, p. 13). It is composed typically of several types of landscape elements (i.e. patches). Patches represent relatively discrete areas of comparatively 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, pp. 3-4).

However, a landscape is generally considered a broad portion of a territory (Farina, 1998, p. 2).

Landscape structure is a result of the complex interactions between physical, biological, political, 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, p. 11).

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, p. 10). 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, p. 11). Hence, it could be quantified using shape, nearest neighbour, contagion and interspersion statistics. Gustafson (1998) provides a comprehensive review of studies related to quantifying landscape spatial patterns.

Riparian landscapes are made up of patches or corridors of distinct vegetation types, wetlands, and other land uses such as agricultural crops, pasture, and urban settlements. They are unique environments because they are terrestrial habitats that both strongly affect and are influenced by aquatic environments, they have particular spatial configurations, they have use values derived from these features and they are diverse in their structure and function among regions (Malanson, 1993, p. 12).

The riparian vegetation plays a significant role in relation to soil erosion, channel stability, wildlife and fish habitat, and water quality (Kuusemets and Mander, 1999; Vought et al., 1995; Gregory et al., 1991). Forests in riparian areas also have important roles in regulating the upstream-downstream movement of matter and energy by filtering or stopping the movement of sediments, water and nutrients. Specifically, riparian vegetation has an important filtering role for dissolved nitrogen, phosphorous, and toxins moving along the slope discharge. For instance, Correll, et al. (1992), found that riparian forest bordering agricultural fields removed over 80% of the nitrate and total phosphorous in overland flooding, and about 85% of nitrate in shallow groundwater drainage from the cropland.

The landscape features of riparian areas are mainly those of corridors but the features of patches may also apply. As a corridor, a number of measures can be applied including breaks in connectivity and variations in width, nodes or intersections. As a patch, riparian areas can be measured in terms of size, shape, number, and configuration. However, due to the elongated nature of riparian areas and the difficulty of delineating the exact extent of the riparian landscape, it is expected that quantifying and interpreting these landscape metrics will not be straightforward. This study considers these constraints in developing mapping and spatial analysis techniques.

3. Research Methods

3.1. Study Area

The study area selected encompassed a total area of approximately 300,800 hectares of the Lockyer Valley Catchment in south-east Queensland, Australia (Fig. 1). Gatton Shire, the catchment's biggest and most central local government authority, is located approximately 90 km west of Brisbane, the capital city of Queensland. The Lockyer Valley encompasses some of the richest farming land in Australia and supports one of Queensland's most important centres of diversified agriculture. The activities in the catchment principally consist of crop cultivation, cattle grazing and timber production. Pasture dominates the land use/cover types (47%), followed by woody vegetation (41%) and crops (11%). The catchment has a local population of about 22,000 (EPA, 1999).

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) land. Elevation within the catchment ranges from 27 to 1,106 metres above mean sea level. About 55% of the area is developed on sandstone parent materials, while some 25% of the area has been developed on tertiary basaltic flows. On the alluvial plains, highly fertile deep black cracking-clay soils and dark brown clay loams predominate. Elevated areas are typically dominated by shallow, stony, sandy or sodic soils with low fertility.

An assessment of the catchment (DNR, 1997) found that most stream lengths showed high to moderate disturbance, and riparian vegetation was generally in poor condition. About 41% of stream length was rated "very poor" for riparian vegetation, while 34% was rated "poor". Riparian zones had been cleared for agricultural purposes mostly to the edge of the stream banks, and invasion by exotic species was common. Stream channel habitats displayed low diversity, with aquatic habitats showing low to moderate diversity due to a lack of stream features to provide habitat (EPA, 1999).

3.2. Data Acquisition and Image Processing

The ability to quantify landscape structure is a prerequisite for the study of landscape function and change (McGarigal and Marks, 1994, p. 2). Conversely, the quantification of landscape structure firstly requires delineation or mapping. Thus, mapping is an essential task for any landscape structural analysis. The goal of digital image processing for this study was to produce a reliable land use/cover map for each of the two satellite images (1973 and 1997) acquired for the study area. A flowchart of the techniques employed in mapping and analysis of landscape structural change is given in Fig. 2. The GIS provided the environment where the raster images and other thematic maps were pre-processed, displayed and analysed. Both major tasks employed the GRID module of ARC/INFO Revision 7 and ArcView 3.1 Spatial Analyst GIS software (ESRI, 1996; 1997).

A 75 km x 66 km subset was selected from a Landsat 5 Thematic Mapper (TM) digital image, taken on September 1997. The same image extent was utilised for the

August 1973 Landsat 1 Multispectral Scanner (MSS) data. Unlike the raw MSS image, the TM image was acquired as a geometrically rectified product with a reported maximum root mean square error of 20 metres. For the 1997 TM image, all the visible and non-thermal infrared bands 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). All four bands were used from the 1973 MSS image, as well as an NDVI image.

A detailed account of the image processing techniques employed in this study is reported in Apan et al. (2000). The 1973 and 1997 images were classified by adopting a post-classification change detection method, which used spatial masking and supervised classification techniques (employing a maximum likelihood classifier with prior probabilities). The final classification yielded five classes for each image: woody vegetation, pasture, crops, settlement, and water. These class definitions were adopted, after modification, from the Queensland's Statewide Land Cover and Trees Study (SLATS) project (DNR, 1999).

Previous studies (e.g. Benzon and Mackenzie, 1995; Moody and Woodcock, 1995) have indicated that sensor spatial resolution may have an effect on landscape structure parameters. To minimise any effect, a broader level of classification was used along with a region-based generalisation procedure for the finer 30-m Landsat TM image, after classification. Both images were also resampled to 50 m, bringing the TM image to a coarser spatial resolution (Barnsley et al., 1997).

3.3. Analysis

Other data sets required for the study, i.e. digital elevation model (DEM), catchment boundary, and digital cadastral data base (DCDB), were acquired from the Queensland Department of Natural Resources. The stream network map generated from the DEM was used to derive the Strahler's (1957) system of stream ordering. Fixed and variable width buffering (details described below) was applied to the stream data to generate riparian buffer zones. The DCDB was used to derive the land tenure map. Clipped to the extent of the catchment boundary, all data sets were converted into raster data format so that the analysis could be implemented in tandem with the land use/cover maps derived from the satellite images.

The delineation of the exact extent and boundary of the riparian landscape is often difficult (and remains an issue of debate) with the riparian vegetation corridor often being indistinct. This problem is compounded as riparian landscapes often have different longitudinal structures (i.e. from headwaters to the mouth of rivers) as well as transverse structures (i.e. the cross section of the flood plain), whose functions and effects to ecological processes vary considerably (Harper et al., 1999; Boon, 1998). Thus, buffering was used in the absence of a more reliable and less complicated mapping technique for the riparian zones.

The following options for stream buffering were implemented in this study: a) fixed width buffering of all major streams (i.e. 50 m buffer for all 4th-, 5th- and 6th-order streams), and b) variable width buffering based on Strahler's stream ordering (i.e. 200 m for 1st- order, 100 m for 2nd- to 4th- order, and 50 m for all streams greater than the

4^{th}- order. Although the choice of the specific buffer distances used is partly arbitrary, the relative magnitude of these widths was based on field observation and recommendations provided by Forman (1997, p. 245).

In this study, quantifying riparian landscape structure and its change over time involves the use of statistical measures (also called “metrics” or “indices”) that describe the landscape configuration and composition. The program Patch Analyst (Grid) 1.1 (Rempel, et al., 1999), which is an extension to the ArcView GIS system, was used to generate 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 focused principally on the woody vegetation class and utilised: a) area metrics; b) patch density, patch size and variability metrics; c) shape metrics; d) nearest-neighbor metrics; e) diversity metrics; and f) contagion and interspersion metrics.

A map overlay in GIS was performed to create a thematic map depicting all the possible combinations of land use change (e.g. pasture to agricultural crops, woody vegetation to settlement, etc.) between the 1973 and 1997 images. All changes in the riparian buffer zones involving woody vegetation (i.e. from woody vegetation to pasture, agricultural crops, etc.) were mapped and analysed. Furthermore, the areas of riparian vegetation change covering the variable width buffer zone were overlaid independently with land tenure, stream order, and slope maps. These characteristics were specifically selected due to their likely effect on vegetation change or their ecological importance. Tree clearing policies in Queensland are specific to the tenurial status of the land. Freehold landowners have until recently, been able to clear trees at will as government regulations were previously non-restrictive. Stream order, on the other hand, is relevant to certain biological, ecological and hydrologic processes operating in the streams and adjoining riparian corridors (Forman, 1997, pp. 213-245). For example, first-order streams have a sponge effect on hydrologic flows, minimising downstream flooding. Lastly, slope information is related to many bio-physical processes including soil erosion (Wischmeier and Smith, 1978).

The relationships between vegetation clearing and land tenure were further assessed using the Pearson chi-square test and Cramer’s V statistic. The former is a common test of association used to assess whether the row and column variables of a two-way table are independent of each other (Dytham, 1999, p. 147). The hypothesis of statistical independence is rejected if the Pearson chi-square statistic exceeds or equals the critical value at α level of significance for certain degrees of freedom. Cramer’s V is a measure of the magnitude of association with its values ranging from 0 (no relation between factors) to +1 (perfect relation between the two factors).

4. Results

4.1. Riparian Vegetation Clearing

The results (Table 1) show that woody vegetation was cleared mainly for pasture, comprising approximately 35% to 36% of the total buffer zones. Between the period

1973 and 1997, about 1,236 hectares and 16,139 hectares of woody vegetation areas were cleared for pasture in the fixed and variable width buffer zones, respectively. Only minor clearing occurred for agricultural crops or settlements.

Approximately 11,821 ha (equivalent to 72% of the total area cleared) in the riparian zone was cleared within the first order stream network (Fig. 3). In contrast, 300 ha of woody vegetation was cleared in areas corresponding to >4th -order streams. First-order streams are principally located in the upland areas or mountain reaches, while higher order streams are found on lowlands or plains. With regards to slope, approximately 65% of vegetation clearing occurred on flat to moderately steep slopes, i.e. 0 to 18% slope (Fig. 4). On the other hand, vegetation clearing on steep to very steep slopes (above 18%) was still prevalent, corresponding to a total area of 5,837 ha (35% of the total cleared area).

Approximately 14,357 ha of woody vegetation was cleared from freehold land during the study period (Table 2). This corresponds to 39% of the total woody vegetation in the freehold tenure riparian zone area (using the variable width buffer). However, only 17% of the woody vegetation in the non-freehold tenure riparian zone area was cleared during the study period. Hence, substantially more woody vegetation clearing occurred on freehold lands (39%) than on non-freehold lands (17%). The results of Pearson chi-square test ($p<0.001$) confirm the association between woody vegetation clearing and land tenure. However, the Cramer's V value suggests that the magnitude of this association is weak (only 0.17 out of 1.00).

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

For the fixed width (50 m) buffer zone, the total woody vegetation cleared was about 1,303 hectares (out of the 6,677 hectares of riparian zone) over the 24-year study period, or an average of 54 hectares per year. Woody vegetation areas decreased from 51% of the landscape to 41% of the landscape over the period. For the area covered by the variable width riparian buffer, the area of the 1973 woody vegetation has also significantly decreased within the 24-year study period. The total woody vegetation clearing (i.e. the 1973 woody vegetation areas converted into other land uses by 1997) was about 16,470 hectares, or an average of about 686 hectares per year (Table 1). The 1997 data (Table 3) showed that the woody vegetation area was only 39% of the total 87,752 hectares, down from 52% in 1973.

The data on patch density, patch size, and largest patch index (Table 3 and Fig. 5) indicated that the riparian vegetation has undergone considerable fragmentation during the study period. The number of patches has increased substantially, particularly for the fixed width (50 m) buffer zone, highlighting the breaking up of vegetation areas into smaller parcels (from 821 to 1,002 patches). While the change in the number of patches was fairly modest for the variable width buffer zone (from 3,398 to 3,412), the mean patch size decreased significantly (ie. from 13.54 to 9.97 ha) and is indicative of the vegetation fragmentation (Fig. 5). Furthermore, the largest patch index of the variable width buffer zone supports this view with the largest woody vegetation patch decreasing from 4.34% to 1.98% of the area.

The mean shape index values for all 1973 and 1997 buffer zones are greater than 1, indicating that many riparian patches are irregularly (non-square) shaped. However, there was no significant change in the shape index values over the study period. For the fixed width riparian buffer zone, the 1997 patches are slightly less irregular in shape than the 1973 patches, i.e. from 1.61 to 1.54. The reverse is true for the variable width buffer zone, although the difference is minimal (from 1.48 to 1.57). The mean patch fractal values suggested a very slight convolution (complexity) of perimeters (from 1.06 to 1.07) for the variable width buffer zone. The values are the same for the fixed width buffer.

4.3. Changes in the Nearest-Neighbor Metrics and Interspersion

The mean nearest-neighbor distance values for the variable width buffer zone have increased from about 107 to 119 m (Table 3). This change indicates that the 1997 woody vegetation patches are more isolated than the 1973 patches, and that inter-patch connectivity has decreased. This is supported by the mean proximity index values (decreased from 93.70 to 79.50). In contrast, the fixed (50 m) width buffer zone has seen a slight increase in inter-patch connectivity (or slight decrease in patch isolation) as indicated by the mean nearest-neighbor distance values (from 110.70 to 102.38 m) and the mean proximity index values (from 10.21 to 10.67).

All 1973 woody vegetation classes have moderate to high interspersion and juxtaposition indices (i.e. 61.38% and 27.56%, for the fixed and variable width buffer zones, respectively). These values indicate that the vegetation patches are well interspersed in the landscape or equally adjacent to all other patch types. In contrast, the 1997 landscapes have much lower values (i.e. 27.56% and 18.78%, for the fixed and variable width buffer zones, respectively), indicating reduced interspersion and juxtaposition to other woody vegetation patches.

5. Discussion

5.1. Riparian Landscape Structure and its Changes

This study suggests that the structure of the riparian landscape in the Lockyer Valley catchment has significantly changed during the 24-year study period. While the 1973 riparian landscape in the study area showed signs of human-induced fragmentation, the 1997 landscape was significantly more fragmented. Within the study period, approximately 16,470 hectares of riparian woody vegetation (in the variable width buffer zone) were converted mainly to pasture. This resulted to the proliferation of much smaller, less connected vegetation patches. This confirms the general trend on land use/cover change in the region observed elsewhere (e.g. Catterall and Kingston, 1993; DNR, 1999) and quantifies for the first time the nature and magnitude of fragmentation of the riparian woody vegetation.

The analysis of vegetation clearing with regards to stream order and slope raises some concerns. First, the rate of riparian vegetation clearing along 1st order streams (mostly headwaters) may have negatively altered (and could still alter) important hydro-ecological conditions and processes, including water velocity, soil erosion, particle size on the stream bottom, degree of shading, presence of dead leaves and water temperature. The sponge effect of first-order corridors also provides the greatest protection against downriver flooding, and helps the control of dissolved-substance inputs from the adjoining lands (Forman, 1997, p. 244). In addition, the absence of vegetation in these areas may exacerbate soil erosion. Similarly, the clearing of vegetation on steep to very steep riparian slopes (>18% slopes) could be expected to have contributed to soil erosion.

The results of the Pearson chi-square test highlighted the statistically significant association between woody vegetation clearing and land tenure. This is consistent with earlier findings (Catterall and Kingston, 1993; DNR, 1999) that the relative rate of clearing on freehold land was significantly higher than leasehold land in south-east Queensland. However, the weak magnitude of association indicates that the degree of correlation between vegetation clearing and land tenure is weak. The Cramer's V value of 0.17 means that only 3% of the woody vegetation clearing is explained or predicted by land tenure. Furthermore, as none of the statistical analyses used in this study could provide a direct measure of causality, the interdependence of land tenure and vegetation clearing could not be directly ascertained.

Because of the two-date (1973 and 1997) satellite imagery used, only two-way landscape patterns could be observed (i.e. vegetation to pasture, crops to settlement, or vegetation to crops). While this information could be sufficient for simple trend analyses, multi-period mosaic sequences (e.g. vegetation to pasture to crops; vegetation to pasture to vegetation; or pasture to vegetation to crops to pasture, etc.) would be more useful in developing spatially distributed landscape models. In the two-date period used in this study, the final riparian landscape transformation that took place over the study period could be mapped and quantified. However, the two-date change assessment is unable to capture or quantify any intervening or multistage land transformations that took place during the period.

5.2. Implications for Riparian Management

Landscape ecological principles should be included in planning and management of riparian areas to help mitigate the negative effects of development or to restore the functioning of riparian ecosystems. This study has refined processes and identified landscape structure information that could be valuable in riparian zone management for the: (a) identification of stream segments or reaches on which vegetation corridors should be preserved or rehabilitated; (b) prioritisation of riparian areas for immediate management attention; and (c) support of policy formulation pertaining to riparian management and conservation.

Many landscape ecologists and managers stress the need for providing landscape connectivity, especially in the forms of wildlife movement corridors or stepping stones, and in filtering or stoppage of the movement of sediments, water and nutrients (e.g. Dramstad, et al., 1996; Hunter et al., 1999). A basic requirement in ensuring connectivity is to identify prospective riparian areas that need rehabilitation or preservation. The types of datasets, mapping techniques, and spatial analysis and modelling approaches implemented in this study could provide appropriate information for both assessment and planning of revegetation strategies (e.g. Apan and Peterson, 1997). For instance, rehabilitating vegetation corridors would be appropriate where they are non-existent or too narrow to fulfill their natural functions (Piegay and Landon, 1997). Similarly, areas prioritised for preservation could include existing vegetation patches that are close to streams (e.g. 100 m or more).

While it may be relatively easy to identify riparian areas needing preservation and restoration, the prioritisation and implementation of conservation strategies may not be straightforward. Other land factors need to be considered as part of the process including land ownership and tenure, slope, and stream order. Land ownership and tenure information could indicate opportunities and constraints for the restoration and preservation of riparian forests. Perhaps, if all other factors are equally relevant, government or state owned lands could be better prioritised than private lands because of the costs and tenurial constraints. For example, in a study in California, the preservation or restoration of substantial areas of riparian forest was found to be extremely expensive mainly because of the existing land ownership patterns (Hunter et al., 1999). In considering slope and stream order, degraded non-vegetated areas in first-order streams could be prioritised over other sites to reduce erosion risk and improve water quality.

Landscape structural information, along with conventional land use/cover information, can be used to support policy formulation pertaining to riparian management and conservation. Information on vegetation connectivity and fragmentation could assist identification of potential riparian reserves and protection areas. Consequently, locating and profiling “problem areas” could help in developing legislation, policies or programs to speed up rehabilitation and preservation. For example, Queensland legislation has not traditionally provided a mechanism to require farmers to implement riparian revegetation. Hence, there may be a need for subsidies, tax incentives and moral suasion (Qureshi and Harrison, 2001).

Deciding on the width of the stream corridor is perhaps the most important decision a land use planner or resource manager could face in designing riparian zone management plans. Because external stresses on the corridor, such as the input of dissolved substances, are uneven along its length, good design and management practices often require uneven corridor widths (Forman, 1997, p. 245). In most situations, the determination of the optimum width for a particular management objective is not trivial – various factors such as land use, slope, rainfall, stream order, existing riparian vegetation, landform, and geology, must be thoroughly considered. GIS is an environment where spatial datasets corresponding to these factors could be assembled, integrated and analysed.

5.3. Mapping and Landscape Metrics Calculations

Visual image interpretation of contrast-enhanced Landsat TM and MSS images (e.g. TM 3, 4, and 5, displayed in blue, green, and red, respectively) were readily differentiated into vegetated and non-vegetated areas. In general, dry bare soil associated with pasture areas have high brightness values in the visible bands and low brightness values in the infrared band, while the reverse is true for healthy, green vegetation. Water bodies were adequately discriminated by visual inspection using pattern and associated location rather than colour. However, topographic shadows (being black) can sometimes be confused with either deep water or wet, dark soils. Hence, the semi-automated spatial masking technique employed in this study was necessary.

The capability of remotely sensed data to delineate between broad-level vegetation areas and pasture (either covered with low-density vegetation or just bare soil) is well established in remote sensing literature (e.g. Singh, 1987; Apan, 1997). The contrasting reflectance properties of these two land use/cover classes in the visible and infrared bands allow their easy differentiation using digital approaches. In addition, the relatively flat riparian areas in major streams avoided the incidence of topographic shadows which is often a serious classification problem and a source of spectral confusion.

This study implemented some measures to address the scale-related problems associated with dissimilar sensor spatial resolutions of Landsat MSS and TM: region-based generalisation, resampling, and adopting a broader level of classification. While these techniques should help 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 these measures. In a landscape structural change assessment involving sensors of different spatial resolution, eliminating or reducing their differences at the desired level is essential. If these differences are not adequately normalized or corrected, the landscape metrics will be unfit for direct multi-date comparison.

Several options for stream buffering were used to quantify riparian landscape structure and its change. While the two methods implemented here (i.e. the fixed 50 m width buffering of all major streams and the variable width buffering based on Strahler's (1957) stream ordering), could have some theoretical and practical limitations in favor of other options, they were considered sufficient for the goals of this study. However, it should be noted that in choosing a buffering method, the major concern is not on whether the different techniques are technically feasible, but on matching the buffering technique with that of the ecological processes and conditions being investigated. Forman (1997, p. 245) presented a framework that could be used as a guide.

Although the Patch Analyst (Grid) and FRAGSTATS programs can generate more than 40 indices, only 13 pre-selected metrics were calculated in this study due to the high correlation amongst these indices and the intensive computing demand. The processing and generation of the landscape metrics was a fairly straightforward task with these packages providing a wide range of indices relevant to landscape structural change analysis. The changes in the land use/cover of a portion of the study area were captured and quantified using the selected landscape metrics with the values being consistent with the observed changes in the riparian vegetation areas (Fig. 5). However, these programs are currently unable to quantify all of the relevant spatial processes in land transformation. For example, no metrics are available that indicate how much an original patch has decreased in size, become perforated, or totally disappeared. The programs have provisions for calculating metrics at an individual patch level, but lack the ability to track changes in individual patches. Where there are only two or three patches in an area, these could be calculated manually. However, considering that many landscapes cover a large area and include numerous irregularly shaped patches, the development of automated techniques is preferable.

This study considered a range of spatial processes in land transformation and dynamics including fragmentation, perforation, dissection, shrinkage and attrition. For example, a vegetation patch may have shrunk and became perforated, but did not become fragmented. In the study area, visual examination of the satellite imagery revealed that many riparian vegetation patches decreased in size, disappeared, were dissected, or became perforated. For instance, a road network (Gatton by-pass) constructed in the late 1970s dissected and subdivided some vegetation patches into sections.

Furthermore, some landscape metrics used in this study, such as the nearest-neighbor and interspersion metrics, may not sufficiently depict the spatial arrangement (and hence the nature and attributes) of riparian vegetation patches. It is possible for two differently patterned riparian corridors to generate similar connectivity and adjacency indices. For instance, similar adjacency metrics can be obtained from the apparently different spatial patterns associated with: a) vegetation patches that are oriented across the stream (i.e. from the river bank to hillslope), and b) vegetation patches that are oriented along the stream (i.e. following the stream). The inability of current indices to distinguish and measure such dissimilar situations may be disadvantageous to some studies or applications. Further research is needed to adequately quantify those aspects of riparian spatial patterns that may have more practical relevance to riparian management.

6. Conclusions

The structure of the riparian landscape in the Lockyer Valley catchment has changed significantly during the 24-year study period. This study quantifies the degenerating condition of the riparian corridors, mainly due to conversion to pasture. The riparian vegetation areas have become more fragmented and are characterised by the proliferation of much smaller, less connected vegetation patches. The management of riparian areas, particularly the identification and prioritisation of stream segments for rehabilitation and preservation, and the development of supporting policies, could be expected to benefit from the use of landscape structure information.

The implementation of policies that will ban or strictly limit vegetation clearing in freehold lands could not be adequately supported by the findings of this study. While more woody vegetation clearing occurred in freehold lands than in non-freehold lands, the proportional difference is not large enough to produce a strong correlation. Further studies covering a wider area are necessary to develop a better understanding of the relationships between woody vegetation clearing, land tenure and other land factors. However, the large proportion of woody vegetation cleared within the riparian zone on steep slopes (>18%) or along first-order streams raises serious questions in relation to both the catchment health and the longer term potential for land degradation by upland clearing.

Satellite imagery and GIS provided the information base, environment and analytical tools to visualise and quantify landscape structural changes simply and quickly. 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 normalisation techniques are used to address this problem, quantitative indicators of their performance are necessary. Lastly, while current GIS 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 for more complex landscape structural change analysis.

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Table 1
Woody vegetation change (1973 and 1997) in the riparian zones of the Lockyer Valley Catchment

Woody Vegetation Change	Fixed Width (50 m) Buffer Zone		Variable Width Buffer Zone	
	Area (ha)	%	Area (ha)	(%)
A. No change	2,114	61.86	29,558	64.22
B1. Woody Vegetation to Pasture	1,236	36.16	16,139	35.06
B2. Woody Vegetation to Crops	60	1.77	295	0.64
B3. Woody Vegetation to Settlement	7	0.20	10	0.02
B4. Woody Vegetation to Water	0	0	26	0.06
Total of B1-B4	1,303	38.14	16,470	35.78
Grand Total (A and Bs)	3,417	100	46,027	100

Table 2
Vegetation clearing (1973 to 1997) and land tenure in the riparian zones (variable width) of the Lockyer Valley Catchment

Woody Vegetation	Freehold Land		Non-freehold Land[*]		Total	
	Ha	%	Ha	%	Ha	%
No change	22,427	61	5,845	83	28,272	65
Changed	14,357	39	1,176	17	15,534	35
Total	36,785	100	7,021	100	43,806[**]	100

[*] includes Leasehold, State Forest, Reserve, National Park, Railway, State Land, Water Resource, and Action Pending; they grouped together for the purpose of analysis

[**] this will not coincide with the total woody vegetation area (46,027 ha) in Tables 1 and 3 due to the areas covered by roads and streams.

Table 3
Riparian landscape structural change indices for the Lockyer Valley Catchment, 1973-1997

Indices	Fixed Width (50 m) Buffer Zone		Variable Width Buffer Zone	
	1973	1997	1973	1997
TOTAL LANDSCAPE AREA (ha)	6,677	6,677	87,752	87,752
CLASS LEVEL: Vegetation				
Class Area (ha)	3,417	2,726	46,027	34,018
Percent of Landscape (%)	51.16	40.85	52.45	38.76
Number of Patches	821	1,002	3,398	3,412
Patch Density (# / 100 ha)	12.30	15.01	3.87	3.89
Mean Patch Size (ha)	4.16	2.72	13.54	9.97
Patch Size CV[a] (%)	359	314	610	501
Largest Patch Index[b] (%)	5.37	2.86	4.34	1.98
Mean Shape Index[c]	1.61	1.54	1.48	1.57
Mean Patch Fractal[d]	1.07	1.07	1.06	1.07
Mean Nearest Neighbor Distance (m)[e]	110.70	102.38	107.32	119.38
Nearest Neighbor CV (%)	154	125	96	125.64
Mean Proximity Index[f]	10.21	10.67	93.70	79.50
Interspersion/Juxtaposition (%)[g]	61.38	42.85	27.56	18.78

[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 (due to raster cell structure); it increases without limit as the patch shapes become more irregular

[d] it approaches 1 for shapes with very simple perimeters such as circles; 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] it is equal to 0 if all patches of the corresponding patch type have no neighbours of the same type within the search radius (50 m in this study); it increases as patches become less isolated and the patch type becomes less fragmented

[g] 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

The above explanations were based from McGarigal and Marks (1994, Appendix C).

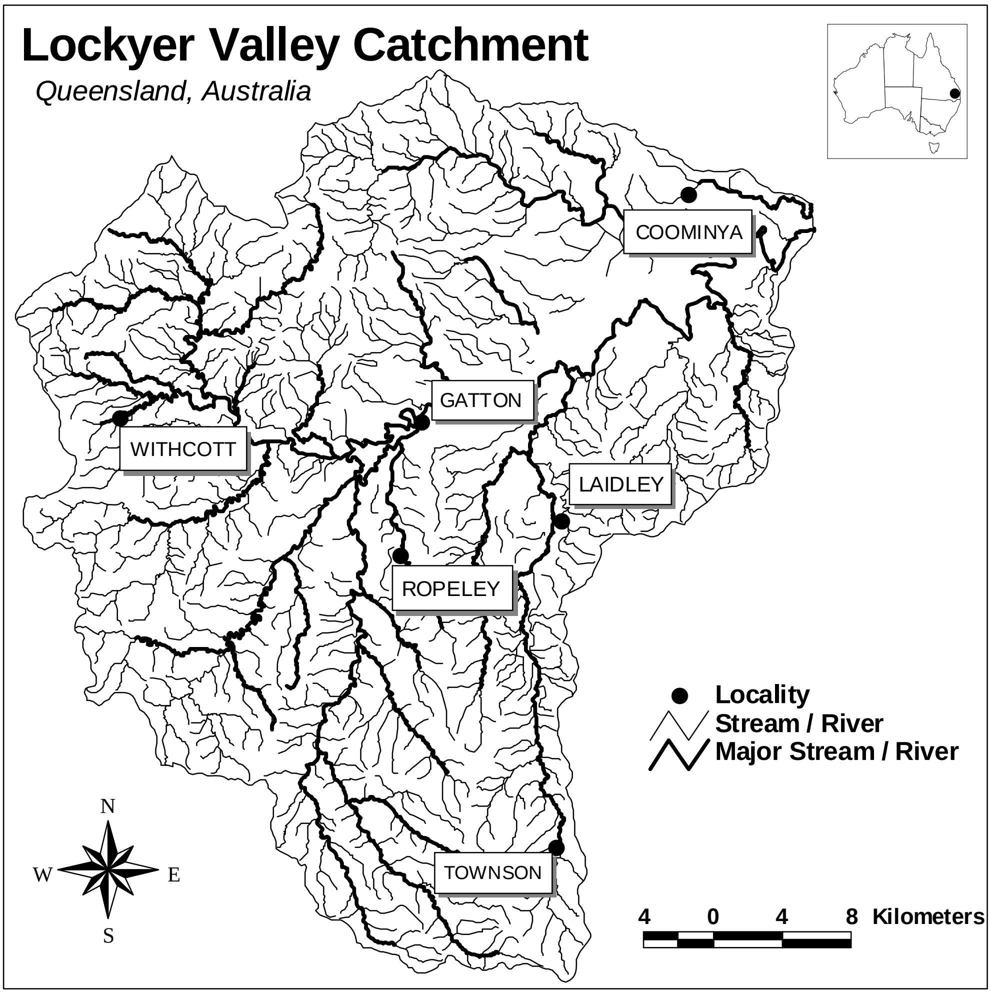


Fig.1. Location map of the study area

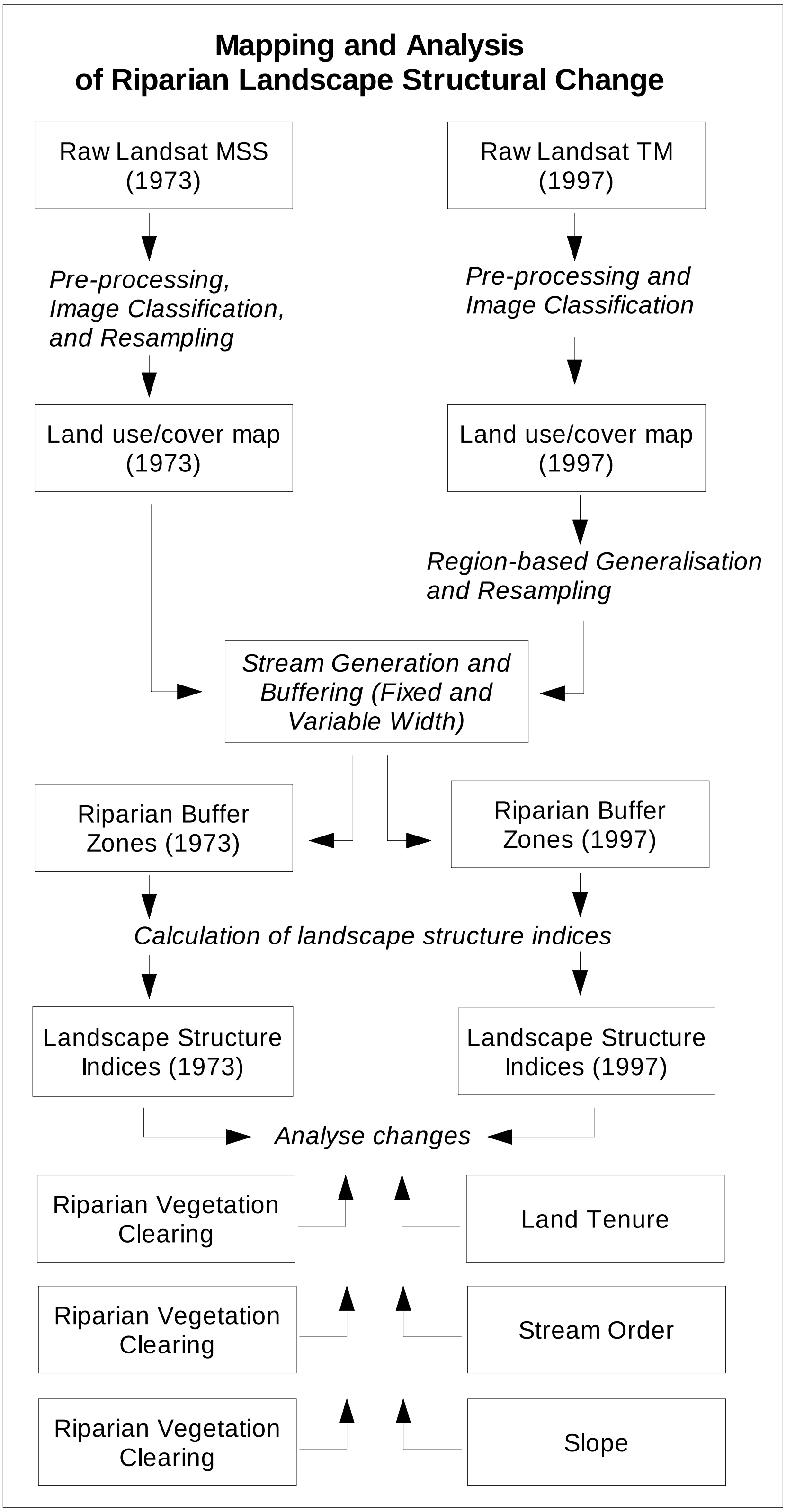


Fig. 2. Major steps in mapping and analysis of landscape structural change

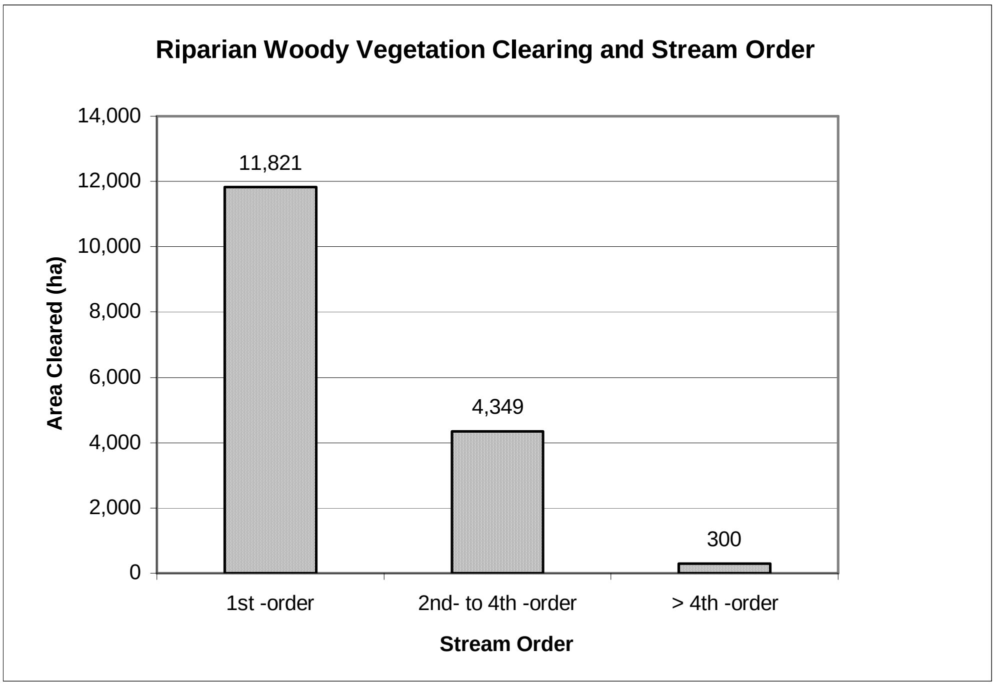


Fig.3. Woody vegetation clearing (1973 and 1997) and stream order

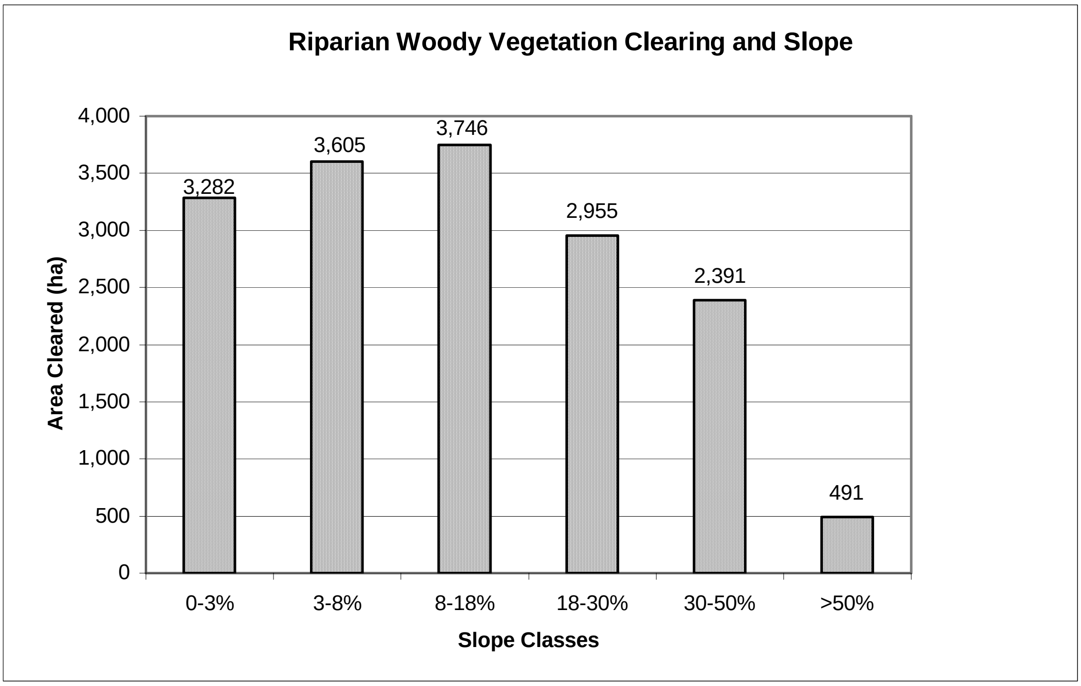
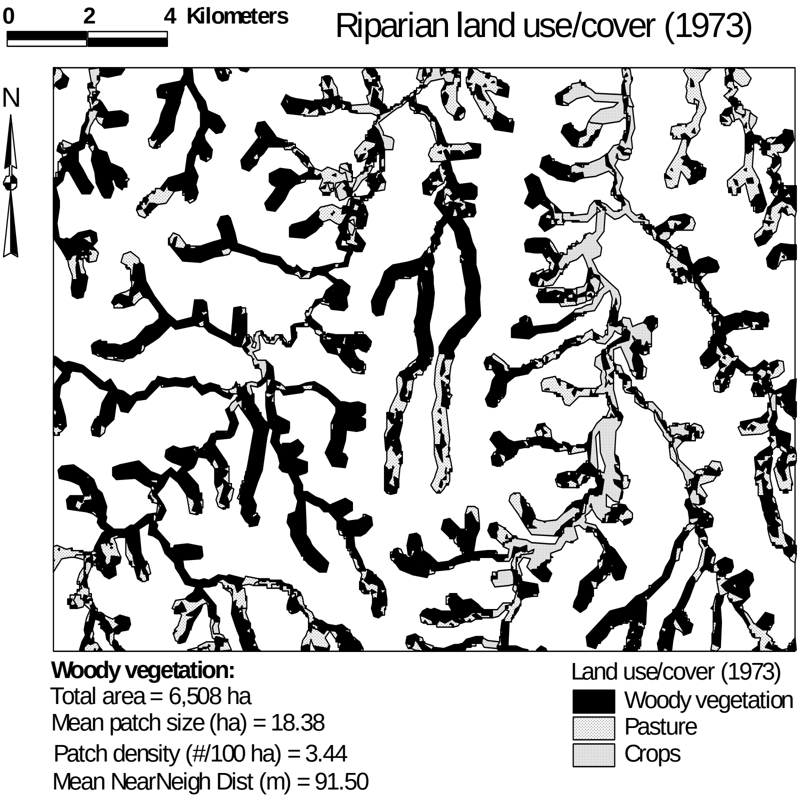
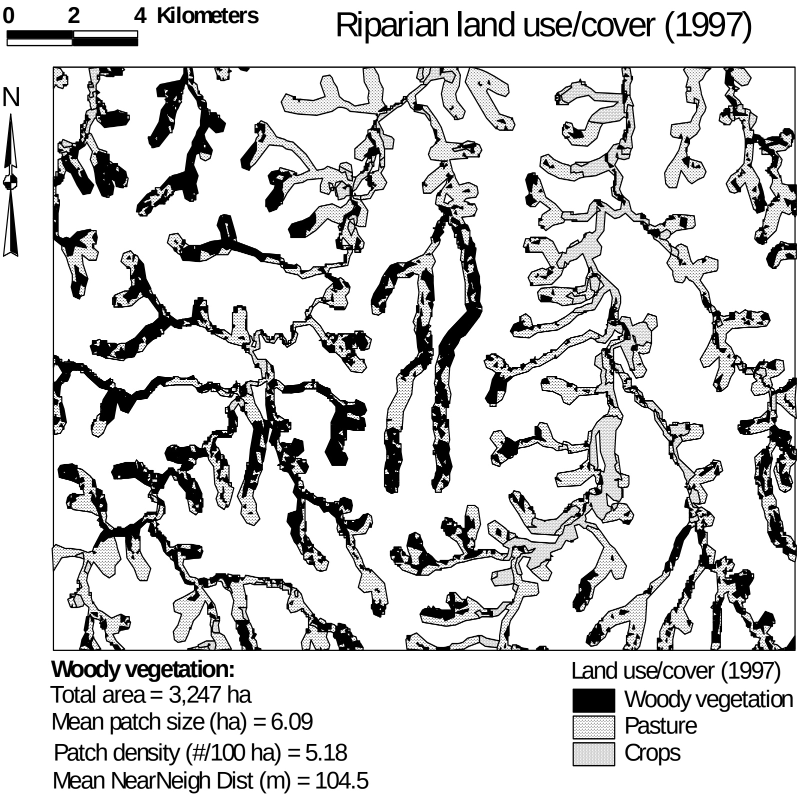


Fig. 4. Woody vegetation clearing (1973 and 1997) and slope



Woody vegetation:
Total area = 6,508 ha
Mean patch size (ha) = 18.38
Patch density (#/100 ha) = 3.44
Mean NearNeigh Dist (m) = 91.50



Woody vegetation:
Total area = 3,247 ha
Mean patch size (ha) = 6.09
Patch density (#/100 ha) = 5.18
Mean NearNeigh Dist (m) = 104.5

Fig. 5. Changes in land use/cover and selected landscape metrics in a portion of the study area (variable width buffer zone)