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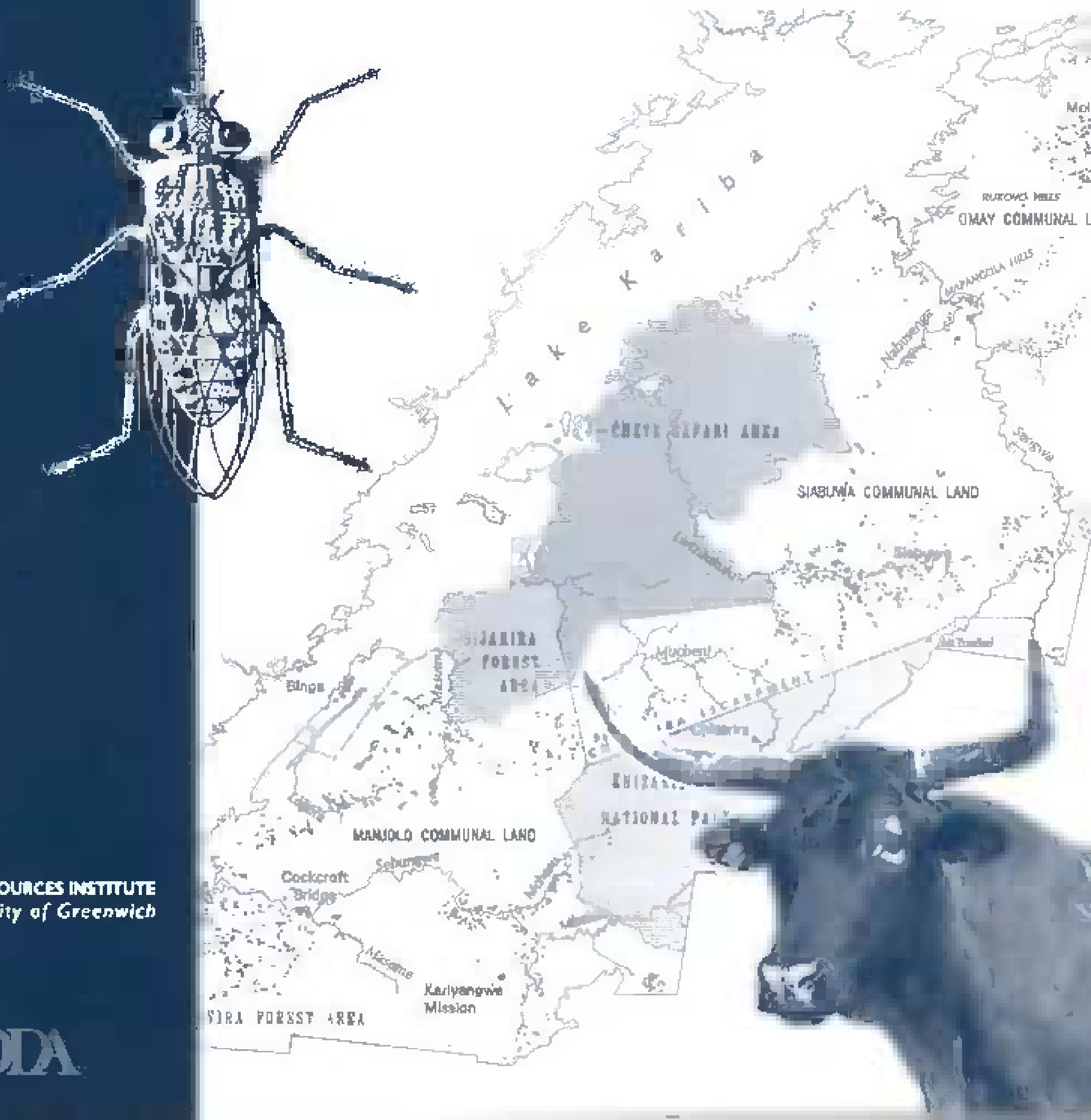
Phase 2: Analysis of Land Use Change by Remote Sensing Imagery



NATURAL RESOURCES INSTITUTE
The University of Greenwich

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IMPACT OF TSETSE CONTROL ON LAND USE IN THE SEMI-ARID ZONE OF ZIMBABWE

Phase 2: Analysis of Land Use Change by Remote Sensing Imagery

J Pender, A P Mills and L J Rosenberg

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The Natural Resources Institute (NRI) is a scientific institute within the University of Greenwich, and is an internationally recognized centre of expertise in research and consultancy in the environment and natural resources sector. Its principal aim is to increase the productivity of renewable natural resources in developing countries in a sustainable way by promoting development through science.

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Contents

Summaries

SUMMARY

Tsetse control is carried out to facilitate the expansion of livestock-based production systems in areas cleared of the threat of bovine trypanosomiasis. There is a growing awareness of the need for tsetse control to be considered an integral component of rural development and of the importance of monitoring and evaluating both the causes and consequences of potential land-use changes as a prerequisite for planning control operations. As part of an international programme to evaluate the environmental and socio-economic effects of tsetse control in southern Africa, changes in land cover over a 20-year period are being assessed in an area of Zimbabwe with a long and varied history of tsetse control and agricultural development. The study area, adjacent to Lake Kariba, covers approximately 8300 km^2 and comprises Reserved, Communal and State Lands. The first phase of the study established the baseline land-use and vegetation patterns, using satellite imagery. In Phase 2, changes in land cover, particularly human-dominated land use (HDLU), are examined from 1972 to 1993, using four Landsat TM and five MSS images, integrated with other datasets in ARC/INFO GIS.

Seven land cover classes were derived—four woodland groups, two related to grass and naturally occurring bare soil and a HDLU class. Only 1.8% of the total land cover was permanently under HDLU throughout the study, although the proportion varied between 5.7% and 9.7%. In general, there had been a fairly steady increase in the proportion of HDLU throughout the study period, interspersed with periods of decrease or little change, but underlying this apparent relative stability there was a pattern of highly variable change with simultaneous expansions and contractions on many fronts and considerable differences in the pattern of HDLU change between the different Communal Lands and between the Communal and State Lands. Similar proportions of the four woodland vegetation classes were affected by changes in HDLU, although there were pronounced local differences. Importantly, agricultural land abandoned in *Colophospermum mopane* woodland did not regenerate into mopane woodland but into mixed woodland or scrub during the 20-year study period. There is little evidence of a direct relationship between patterns of HDLU change and either tsetse control operations or changes in livestock numbers and composition, indicating that there is a complex series of factors, including tsetse control, which influence agricultural development in the area.

RESUME

La lutte contre la mouche tsé-tsé est menée à bien pour faciliter l'expansion de systèmes fondés sur l'élevage dans les régions où la menace de trypanosomiase bovine a été éliminée. On est de plus en plus conscient de la nécessité de considérer la lutte contre la mouche tsé-tsé comme une partie intégrante du développement rural et de l'importance de surveiller et d'évaluer à la fois les causes et les conséquences des changements potentiels d'utilisation des terres, en tant que condition préalable à la planification des opérations de lutte. En tant que partie d'un programme international visant à évaluer les effets socio-économiques et les effets sur l'environnement de la lutte contre la tsé-tsé en Afrique australe, les changements de couvert des terres sont évalués sur une période de 20 ans dans une région du Zimbabwe, dont l'historique de la lutte contre la tsé-tsé et du développement agricole est long et varié. La zone d'étude, contiguë au Lac Kariba, couvre près de 8300 km^2 et comprend des terres de réserves, des terres communales et étatiques. La première phase de l'étude établissait les types d'utilisation des terres et les types de végétation d'origine, à l'aide d'images obtenues par satellite. Dans la phase 2, les changements de couvert des terres, et en particulier l'utilisation des terres par l'Homme (HDLU), sont étudiés de 1972 à 1993, avec quatre images obtenues par Landsat TM et cinq images obtenues par MSS, intégrées à d'autres ensembles de données dans le SIG ARC/INFO.

Sept catégories de couvert des terres en ont été tirées—quatre groupes de terres boisées, deux catégories ayant trait aux herbages et au sol dénudé existant naturellement et une catégorie d'utilisation des terres par l'Homme. 1,8% seulement du couvert total était utilisé en permanence par l'Homme dans l'ensemble de l'étude, bien que la proportion varie entre 5,7% et 9,7%. En général, il y a eu un accroissement relativement régulier de la proportion des terres utilisées par l'Homme tout au long de la période d'étude, entrecoupé de périodes de déclin ou de peu de changement. Mais, sous-jacent à cette stabilité relative apparente, le mode de changement était très variable avec des expansions et des contractions simultanées sur de nombreux fronts et des différences considérables de type de changement de l'utilisation des terres par l'Homme entre les différentes terres communales et entre les terres communales et les terres étatiques. Des proportions similaires des quatre catégories de terres boisées étaient affectées par les changements de l'utilisation des terres par l'Homme, bien que des différences locales prononcées existent. Il est important de noter que les terres agricoles abandonnées dans les terres boisées à *Colophospermum mopane* ne se régénéraient pas en terres boisées de type mopane mais en terres boisées mixtes ou en broussailles au cours de la période d'étude de vingt ans. Il existe peu de preuves d'un rapport direct entre les types de changement de l'utilisation des terres par l'Homme et les opérations de lutte contre la tsé-tsé ou les changements du nombre de têtes de bétail et de la composition du bétail, ce qui indique qu'une série complexe de facteurs, incluant la lutte contre la tsé-tsé, influence le développement agricole dans cette région.

Introduction

Bovine trypanosomiasis transmitted by tsetse fly (*Glossina* spp.) is a major constraint to rural development and livestock production in Zimbabwe. Areas below about 1100 m are climatically suitable for tsetse and approximately half the country has a long history of infestation (Lovemore, 1994). Since the late nineteenth century, successive governments have attempted to control tsetse by various methods as a means of reducing animal trypanosomiasis. Insecticide spraying started in 1953 and continued until operations were curtailed by the Independence War in the late 1970s, resulting in substantial re-infestation. Large-scale control efforts were resumed in 1982 (Hursey and Allsopp, 1983), so that tsetse are now largely confined to the Zambezi Valley and the northern border with Mozambique.

Zimbabwe has experienced migrations of people from heavily populated areas to regions cleared of tsetse, particularly since Independence. This influx has been mainly into rural peasant farming areas (Communal Lands) which cover approximately 163 000 km^2 of the country, mainly in areas with less than 650 mm rainfall annually. The human population is growing by about 3% annually in the Communal Lands (Anderson *et al.*, 1993; Zinyama and Whitlow, 1986) and although population density can be as high as 40 persons/km^2 in these areas, the average is less than 10 persons/ km^2 in western Zimbabwe, where remoteness, environmental constraints and the presence of tsetse have limited immigration and population growth (Zinyama and Whitlow, 1986). This low overall population density, however, masks the dense concentration of population in pockets of more favourable agricultural land in the Zambezi Valley, where increasing population pressure can cause problems, especially where traditional long fallow periods can no longer be sustained (Barrett *et al.*, 1991). Similar relationships between length of fallow period and population pressure have been observed in other parts of Africa (Hunter, 1981) and is an important factor in agro-ecosystem stability (Hunter and Ntriri, 1978).

Mixed farming predominates in the Communal Lands, with individually farmed arable plots of less than 5 ha and communal livestock grazing (Barrett, 1989). Livestock densities can be high, as 63% of the livestock population in Zimbabwe is found in the Communal Lands (Government of the Republic of Zimbabwe, 1992). Livestock introduction into an area is not solely dependent on tsetse control since on-farm (cash cropping) and off-farm (migrant labour, wildlife initiatives) incomes influence livestock numbers as well, as farmers have access to cash revenues which can be invested in the purchase of cattle. Higher cattle numbers can lead to improved access to draught power and the cultivation of larger areas of cash crops (Barrett *et al.*, 1991).

The removal of tsetse can, however, sometimes accelerate livestock productivity and lead to increases in cattle numbers and changes in the composition of livestock herds (Reid, 1994). In some areas of Zimbabwe, tsetse control has, at times, followed the introduction of cattle as a response to attendant increases in disease incidence (Lovemore, 1995). The potential environmental costs of higher stocking rates have not yet been fully evaluated (Scoones, 1992) and the possibility of environmental degradation in tsetse-cleared areas remains a contentious issue, with the Zambezi Valley identified as an area of particular vulnerability (Barrett *et al.*, 1991; Government of the Republic of Zimbabwe, 1992; Jordan, 1992; Ormerod, 1986). There is a growing awareness of the importance of supporting the implementation of tsetse control programmes with resource and economic data on potential land use changes in areas that have been opened up to livestock and settlement (Prankherd, 1991) and of the need for tsetse and trypanosomiasis control programmes to be considered as a support to rural development, rather than as a tsetse eradication exercise (R. Connor, personal communication).

There is, however, little factual evidence on the importance of tsetse clearance on agricultural development and the present study aims to address this omission in western Zimbabwe, in an area approximately 8300 km^2, bordering Lake Kariba. In the first phase of this study (Pender and Rosenberg, 1995), baseline land use and vegetation patterns were defined and quantified using satellite imagery. This second phase examines changes in land cover, particularly human-dominated land use, from 1972 to 1993, using Landsat Thematic Mapper (TM) and Multi-Spectral Scanner (MSS) data, augmented by other datasets from a GIS (Geographical Information System).

The work has been funded by the Overseas Development Administration of the British Government and forms part of an internationally co-ordinated research programme on the socio-economic and environmental impacts of tsetse control in southern Africa. It was carried out in collaboration with the TTCB (Tsetse and Trypanosomiasis Control Branch, Zimbabwe) and ILRI (International Livestock Research Institute) with additional support being provided by RTTCP (Regional Tsetse and Trypanosomiasis Control Programme), WWF (World Wildlife Fund) and Agritex (Department of Agricultural Technical and Extension Services, Zimbabwe).

Analysis of land use change using remote sensing imagery

Remotely sensed data, both analogue aerial photography and digital satellite imagery, have been the primary source of land cover and natural resource information for many years. Their major advantage is the large-scale and uniform coverage they can provide and in the case of satellite-derived data, the increased frequency at which surveys can be repeated (Townshend, 1981), thereby reducing the costs of extensive field work (Tekie and Morton, 1996). The increasing use of digital data in particular, has also sharply focused research into the accuracy of land cover classifications and the interpretation of maps (e.g. Mattikalli, 1995; Michalak, 1993; Molenaar and Janssen, 1992; Trotter, 1991). More recently, the development of computer technology, both hardware and software, has enabled new techniques to be designed for spatial data processing and the integration of remotely sensed information with other data sources that can improve the monitoring and assessment of land cover changes (Michalak, 1993; Molenaar and Janssen, 1992). GIS have been widely recognized as the leading technology for examining the relationships between spatially distributed resources and are the most promising tool for providing timely and reliable information to planners (Michalak, 1993; Trotter, 1991).

Aerial photographs have a higher spatial resolution than satellite images and have been used for many years in detailed studies of land forms, land use and vegetation cover, including research in Zimbabwe on land use change in relation to a broad range of socio-economic factors (e.g. Cumming, 1994; Zinyama, 1988). Aerial photographic surveys remain popular because of the amount of detail and accuracy that can be gained (e.g. Kisoyan, 1996), but the interpretation of large coverages of analogue aerial photographs is expensive and highly specialized, both in terms of data acquisition and interpretation.

Satellite data have been continuously archived since 1972 and hence, provide the potential for historical assessment of changes in land cover, which can then be integrated within a GIS for further analysis. However, many methodological issues have to be addressed before changes can be detected, including the definition of what change is being analysed, the establishment of a suitable baseline from which change can be defined, the spatial and temporal resolution of data, the integration of data from diverse sources held in different data modes (vector and raster), the separation of a linear and cyclic trends and the variance in different sampling or measurement techniques.

Land cover change in Africa has been interpreted at a variety of scales using different satellite-derived data. Studies have ranged from continental, regional and country-wide scales with a spatial resolution of 1.1 to 4 km, using the Advanced Very High Resolution Radiometer (AVHRR) instrument on board the NOAA series of satellites (e.g. Frederiksen and Lawesson, 1992; Fuller *et al.*, 1996; Maseilli *et al.*, 1993; Tucker *et al.*, 1985), to specific area/country-wide studies based on 20 m resolution SPOT XS data (e.g. Makhanya, 1993; Meyer, 1992) or Landsat (30 m resolution for TM, 75 m for MSS) imagery (e.g. Mushove, 1994; Ringrose, 1987; Ringrose *et al.*, 1987, 1988, 1990).

While increased spatial resolution allows for greater mapping detail, there are trade offs with reduced repeat frequency and volume of data processing. NOAA satellites acquire data for the same location daily (for Channel 1 and 2), while Landsat TM has a 16-day and SPOT a 30-day return period. The NOAA-derived high temporal frequency data are useful in the detection and monitoring of wide-scale and seasonal vegetation anomalies (Frederiksen and Lawesson, 1992; Gutman and Ignatov, 1995; Rogers and Williams, 1994; Tucker *et al.*, 1985), but the coarse spatial resolution of the sensor does not allow accurate representation of vegetation changes in areas of mixed agriculture and natural vegetation or where agricultural field size is small or highly variable and fragmented (Marsh *et al.*, 1992). Also, for more permanent changes in land use, a lower frequency of acquisition (e.g. half yearly or less) is probably adequate.

Ideally, remotely sensed data should be chosen which balance the spatial and temporal resolutions of the data with the requirements of the study, although there are limitations in the availability and quality of data from different sources. The detection of land use change can be confused by variation in sensor calibration over time, seasonal illumination effects and seasonal vegetation, farming and burning patterns. Although these effects can be reduced by finding an interval which reflects the speed of change in an area, by acquiring data at the same time of year and from the same sensor, this is not always possible and in reality, studies often have to be based on whatever imagery is available (Mushove, 1994).

Background to the study area

THE PHYSICAL SETTING

The study area covers 8279 km^2 to the east of Lake Kariba and extends from 16°50'S at Bumi Hills to 18°10'S south of Mlibizi and eastwards to approximately 28°E (Figure 1). It covers three areas of Reserved Land (Chete Safari Area, Sijarira Forest Area and most of the Chizarira National Park), parts of the Manjolo and Omay Communal Lands and the whole of the Siabuwa Communal Land and three small areas of State Land along the lakeshore, at Bumi Hills, Mlibizi and Binga (Figure 1).

The study area lies within the Zambezi River drainage system with all rivers draining into Lake Kariba. Elevation ranges from 480 m at the lakeshore to 1439 m at Tundazi, the highest point of the Chizarira Escarpment (Figure 1). The geology ranges in age from Precambrian gneisses and late Precambrian deposits of the Sijarira Group, through the Karoo succession of Permian, Triassic and Jurassic times, to aeolian (Kalahari Sands) and alluvial deposits of Pleistocene and recent origin (Stagman, 1978; Pender and Rosenberg, 1995). On escarpment slopes and in hilly terrain, soils are shallow and poorly developed with many pebbles. Sandy soils of varying depth and quality have developed on fine grained sandstones, while soils on the Kalahari Sand deposits are extremely permeable with little clay content (Pender and Rosenberg, 1995).

The climate is semi-arid with an annual mean rainfall of less than 1100 mm, mostly occurring between October and April, although there are considerable variations between and within years (Pender and Rosenberg, 1995). As in other arid and semi-arid areas of Zimbabwe, single dominance *Colophospermum mopane* woodland and a mosaic of *C. mopane* and *Julbernardia globiflora* woodlands are the predominant natural vegetation in the study area (Boughey, 1961; Cole, 1986; Pender and Rosenberg, 1995). Miombo woodland, dominated by *Brachestygia* spp. and *J. globiflora*, which is the most extensive natural vegetation type in most of the Communal Lands in Zimbabwe (Timberlake *et al.*, 1993), is restricted in the study area to steep escarpments and hills above 1200 m.

Woodland with *Combretum* spp. thickets are prevalent on soils derived from Kalahari Sands in the southwest of the study area and on low escarpments around the plateaux (Pender and Rosenberg, 1995). In some areas, particularly on the Kalahari Sands, *Combretum* spp. form the shrub layer in woodlands with dominant *Guibourtia conjugata* (Timberlake *et al.*, 1993).

HISTORY OF TSETSE CONTROL

Bovine trypanosomiasis transmitted by tsetse flies was prevalent in the study area in the early 1970s (Lovemore, 1995), but successive control campaigns have resulted in the southern limit of tsetse being gradually pushed northwards (Figure 2). The TTCB has also been responsible for developing 70% of all roads in the study area, including access to national parks and game reserve areas, to facilitate access for tsetse control teams (Lovemore, 1995). Not only were new tracks surveyed and constructed by the TTCB, but they were reopened annually as control operations dictated.

In the 1970s, ground spraying operations against tsetse were concentrated in populated areas in the southern part of the Manjolo Communal Land and Binga area (Figure 3), accompanied by improvements to the roads. A cattle fence was also constructed between the Manjolo and Siabuwa Communal Lands to prevent cattle being moved eastwards, since a high incidence of trypanosomiasis was recorded in the Manjolo Store and Kariyangwe area due to infected cattle being brought in from elsewhere. By 1977, the worsening security situation curtailed control operations, although some limited improvements were made to the roads in the southern part of the Chizarira National Park. Trypanosomiasis incidence had increased again when inspections were restarted after Independence in 1980 and cattle numbers had decreased dramatically during the war (Lovemore, 1995).

In spite of the risk of trypanosomiasis and the regulations in force to control cattle movements, cattle were moved back into the Manjolo Communal Land in the early 1980s, either to replace cattle lost to disease, or to return cattle that had been kept outside the tsetse-infested area. Extensive ground and aerial control campaigns were conducted between 1982 and 1985, covering the area between the northern Manjolo and southern Omay Communal Lands (Figure 3) and pushing the southern limit of tsetse fly distribution about 60 km north by 1985, although pockets of tsetse occurrence remained in the south (Figure 2) (Lovemore, 1995). The control operations prompted extensive road development in 1983 and 1984 in the Sijarira Forest Area, Chete Safari Area and the Siabuwa and Omay Communal Lands, continuing in the northern part of the Omay Communal Land until 1989 (Lovemore, 1995).

Control efforts since 1985 have been confined to the northern part of the study area, although some re-infestation southwards has occurred from time to time due to a dense reservoir of tsetse to the north of the Mapangola Hills. A target barrier was used to contain this reservoir and selective ground spraying slowed the spread of tsetse, so that by 1990 tsetse were confined to the northeast of the study area (Figure 2). No new roads have been constructed by the TTCB since 1990.

HUMAN AND LIVESTOCK POPULATIONS

The Communal Lands in the study area are being settled at a rate of about 4% a year (Cumming 1994; Murphree and Cumming, 1993), but population density is amongst the lowest in the country (Anderson *et al.*, 1993; Zinyama and Whitlow, 1986). There is little or no dependence on livestock in the traditional agriculture of the Batonga inhabitants of the region, although since the creation of Lake Kariba and the elimination of tsetse, parts of the area (especially the Manjolo Communal Land) have experienced influxes of people and livestock from elsewhere.

Animal numbers are an order of magnitude greater in the Manjolo compared to the Siabuwa Communal Land (Figure 4) (Department of Veterinary Services, 1994), although data are not available for years between 1986 and 1989. Cattle have always been an important livestock component in the Manjolo Communal Land. Numbers were constant from 1984 to 1985 at just over 20 000 and rose to between 30 000 and 35 000 in the 1990s. Numbers of goats have been more variable, with falling numbers during the 1990–92 drought followed by a sharp increase in 1993 (Figure 4). In contrast, in the Siabuwa Communal Land, where tsetse control was not carried out until the mid-1980s, cattle numbers remained below 1500 until 1994 when there was a sudden increase to more than 4000. Goats in this area also increased during the 1990s (Figure 4). No figures on livestock numbers are available for the Omay Communal Land, but cattle are prohibited in that area.

Materials and methods

LANDSAT IMAGERY AND INTERPRETATION

Landsat TM scene 172/72 and MSS scene 184/72 cover the whole study area. Field surveys in the wet and dry seasons in 1993, combined with black and white aerial photography for 1990 and a Landsat TM image for February 1992 (wet season) were used to determine the baseline land cover of the study area (Pender and Rosenberg, 1995). Although the image was good quality with sharp spectral contrast, it covered a period of drought that had prevailed in southern Africa since 1990, which resulted in an almost complete failure of crops and bare land reflectances similar to a dry season image after harvest. Areas of natural grasses were also dry giving bare soil reflectances. Automatic classification of this image for vegetation type was not possible due to the overwhelming influence of reflectances from bare soil and surface geology. Manual classification with the aid of a GIS, resulted in the identification of fifteen vegetation and human-dominated land use (HDLU) categories (Pender and Rosenberg, 1995).

In order to assess changes in land cover, four TM scenes and five MSS images were obtained from either the historical archives at EOSAT (USA) or the Satellite Applications Centre (RSA) (Table 1). Both MSS and TM imagery were acquired for 20 July 1989, in order to compare directly spectral and spatial differences in the data. The TM imagery acquired was of good quality, as was MSS data for 1986 and 1989. MSS imagery for 1972, 1976 and 1980 was not available in a digital format due to deterioration in the Landsat archive, so film products were obtained for these dates and each band was individually scanned for analysis. The product for 1980 was so poor that it could not be used. A fair quality was achieved with 1972 and 1976 data, although the southwest of the 1972 image was covered by cloud and some

Table 1 Landsat images used in the study

Sensor	Date	Format
MSS	13 9 72	film
MSS	13 8 76	film
MSS	17.11.80	film
TM	22 7 84	digital
MSS	12 7 86	digital
TM	20 7.89	digital
MSS	20 7.89	digital
TM	19.2.92	digital
TM	28.5.93	digital

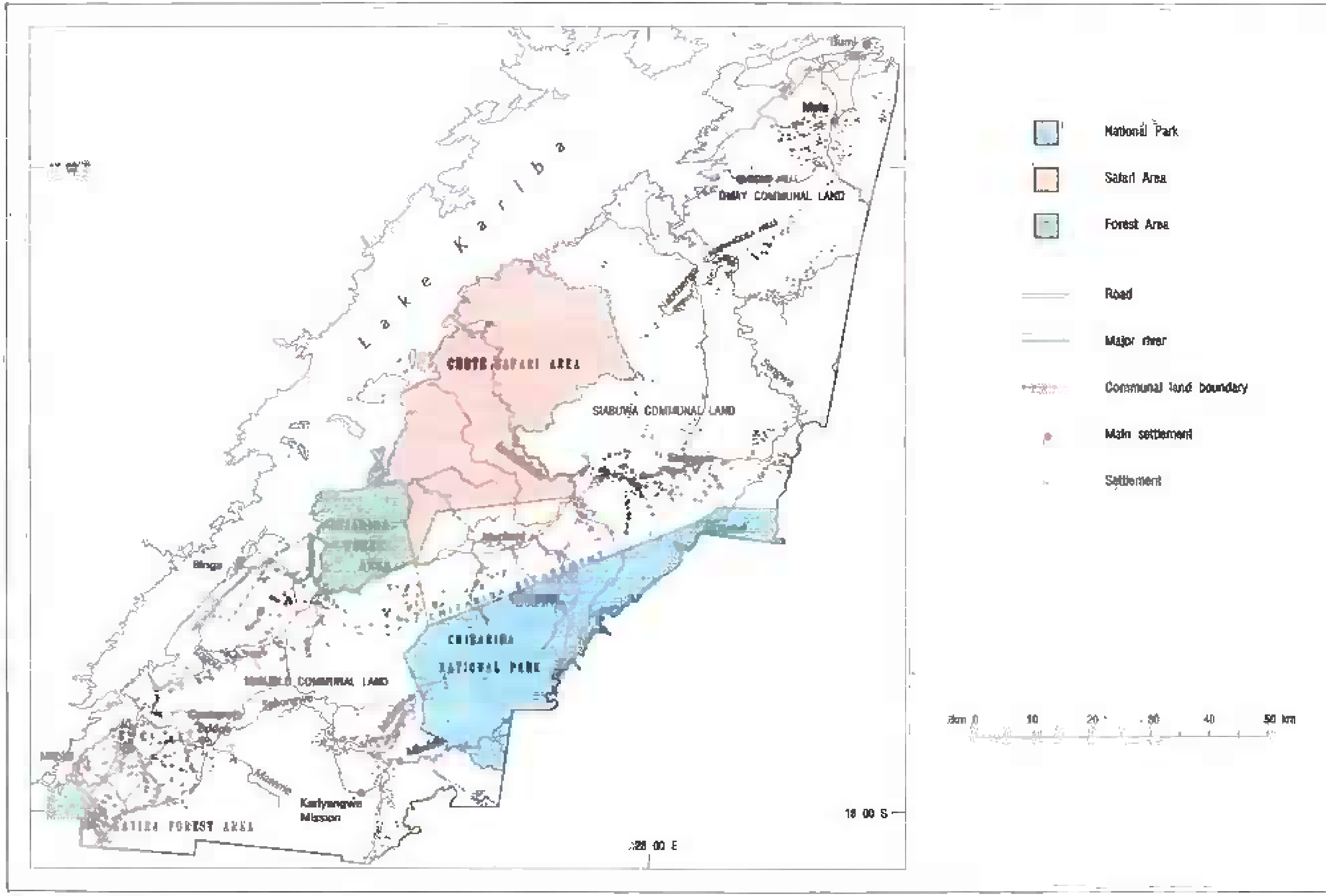

Figure 1 The Lake Kariba study area

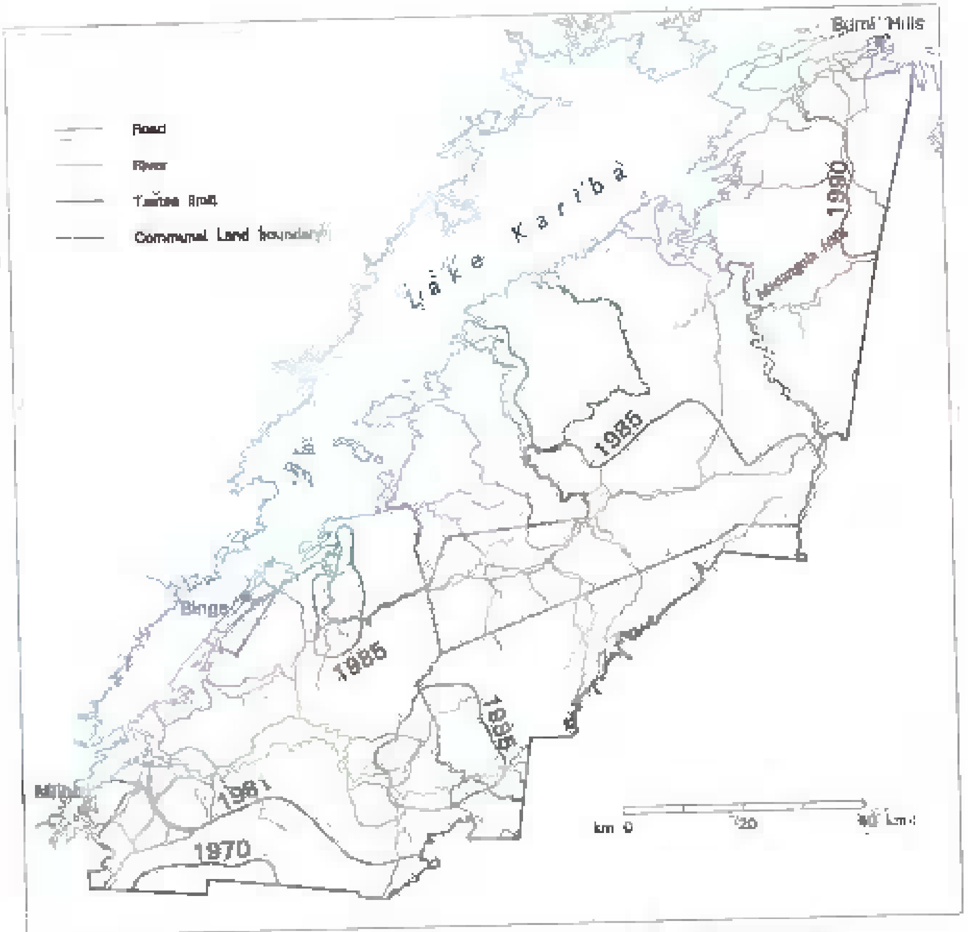

Figure 2 Historical tsetse limits in the Lake Kariba study area

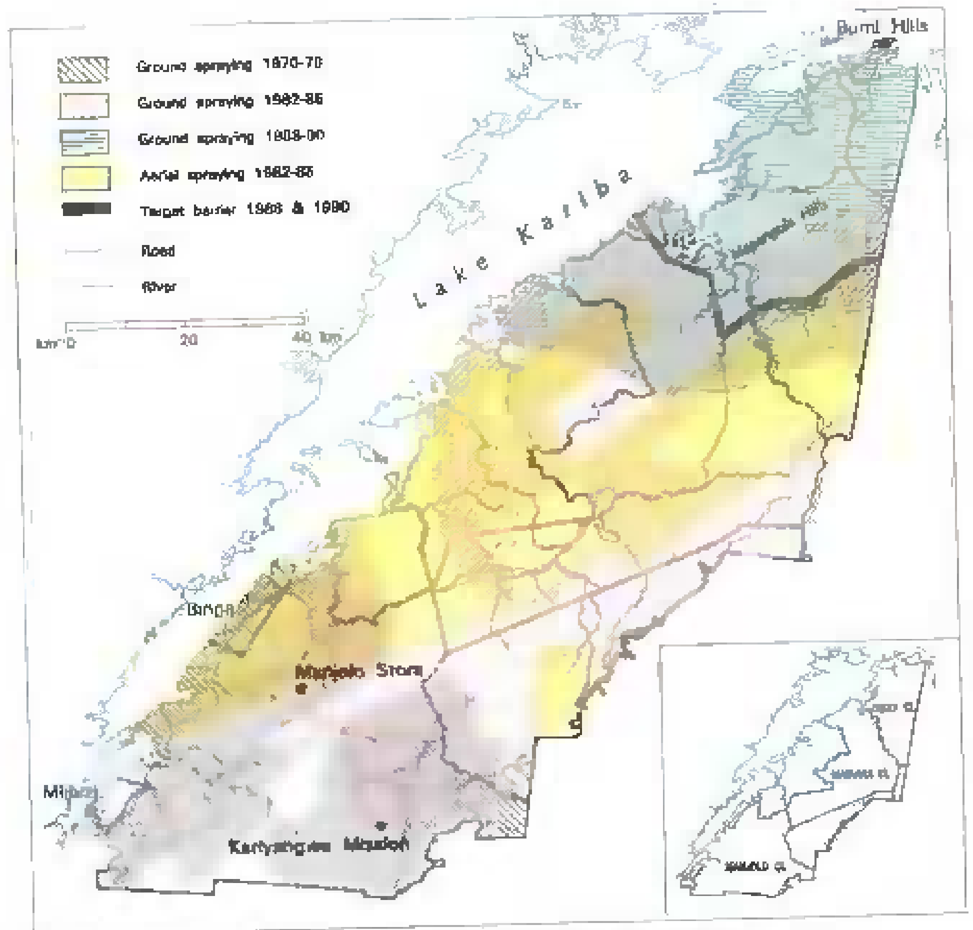

Figure 3 Tsetse control campaigns in the Lake Kariba study area

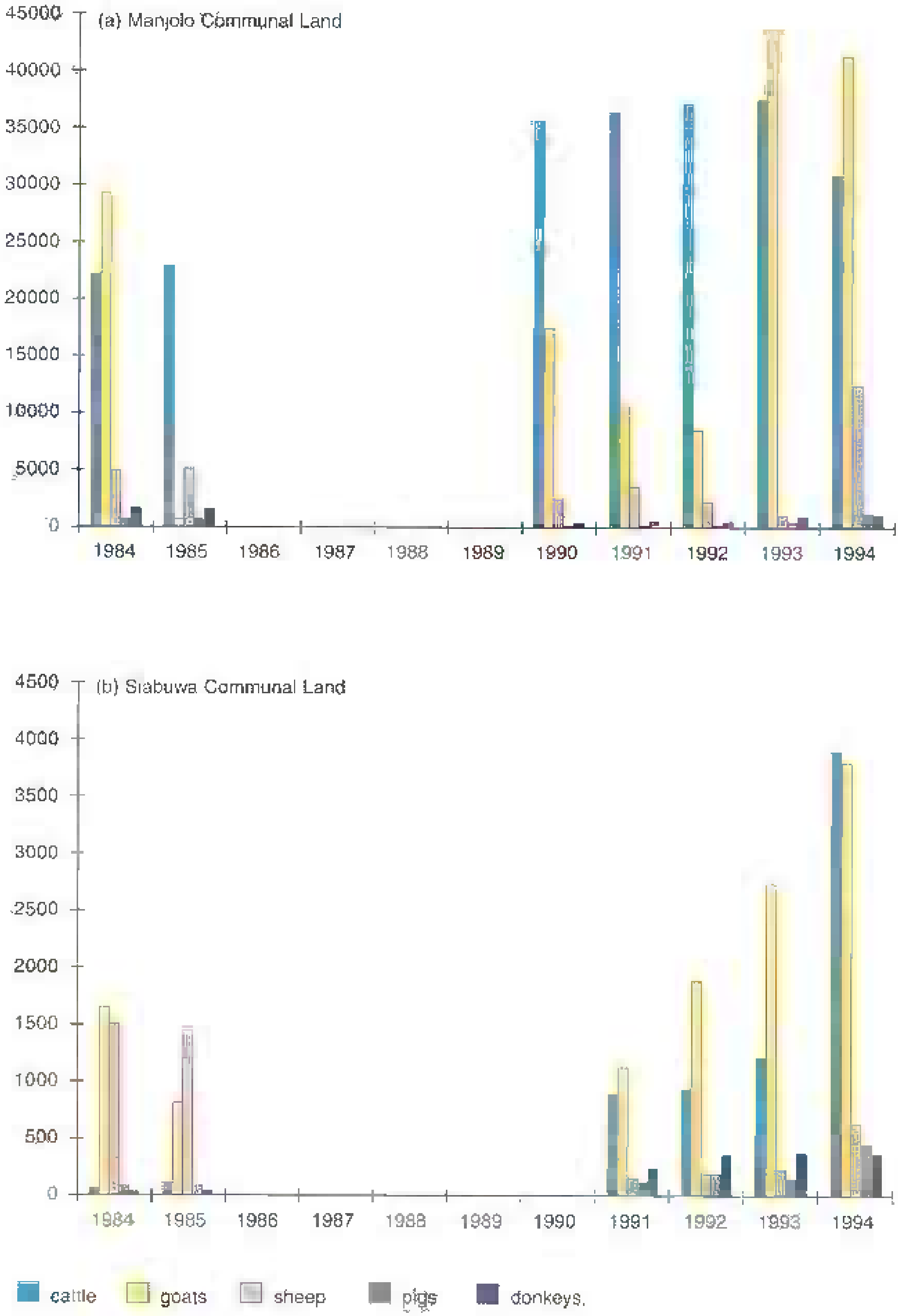

Figure 4. Livestock in (a) Manjolo and (b) Siabuwa Communal Lands

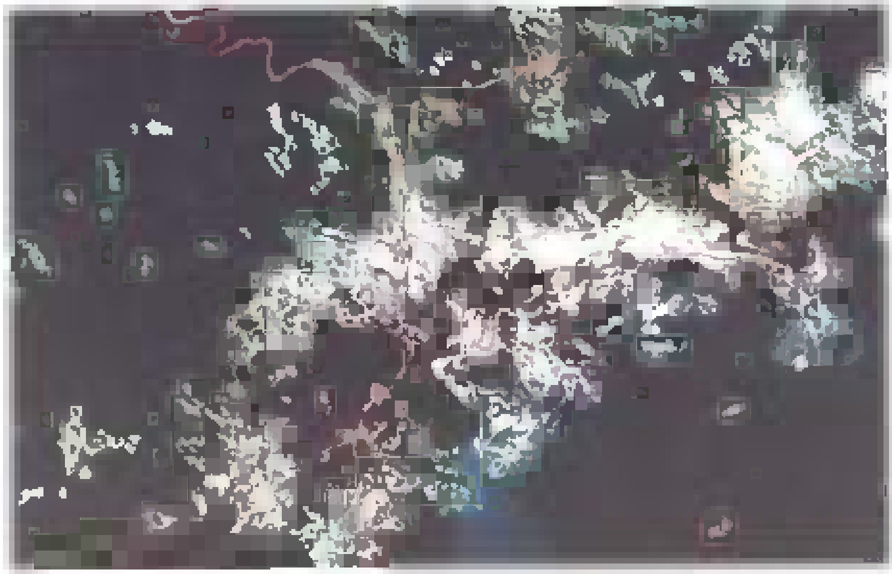

Figure 5 Landsat TM image mask to reduce substrate contrast

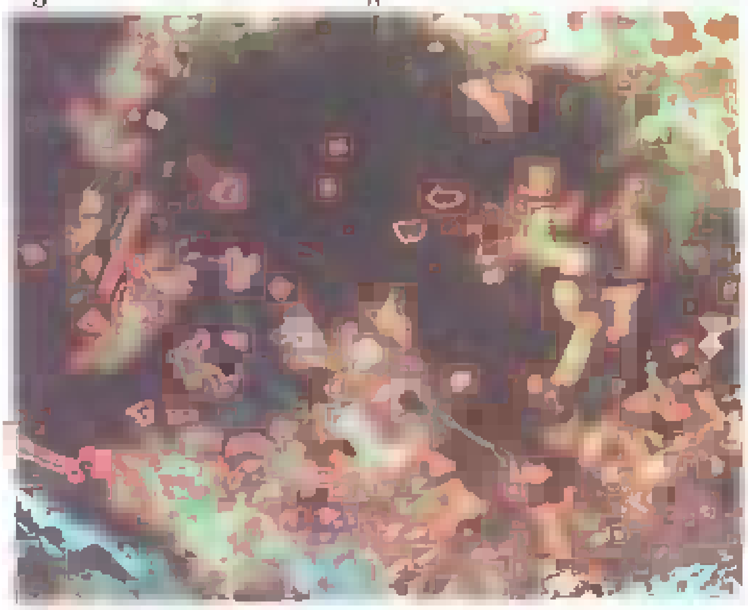

Figure 6 The identification of cultivated fields on a Landsat TM image

Figure 7 The use of a sobel filter to enhance field boundaries on a Landsat TM image

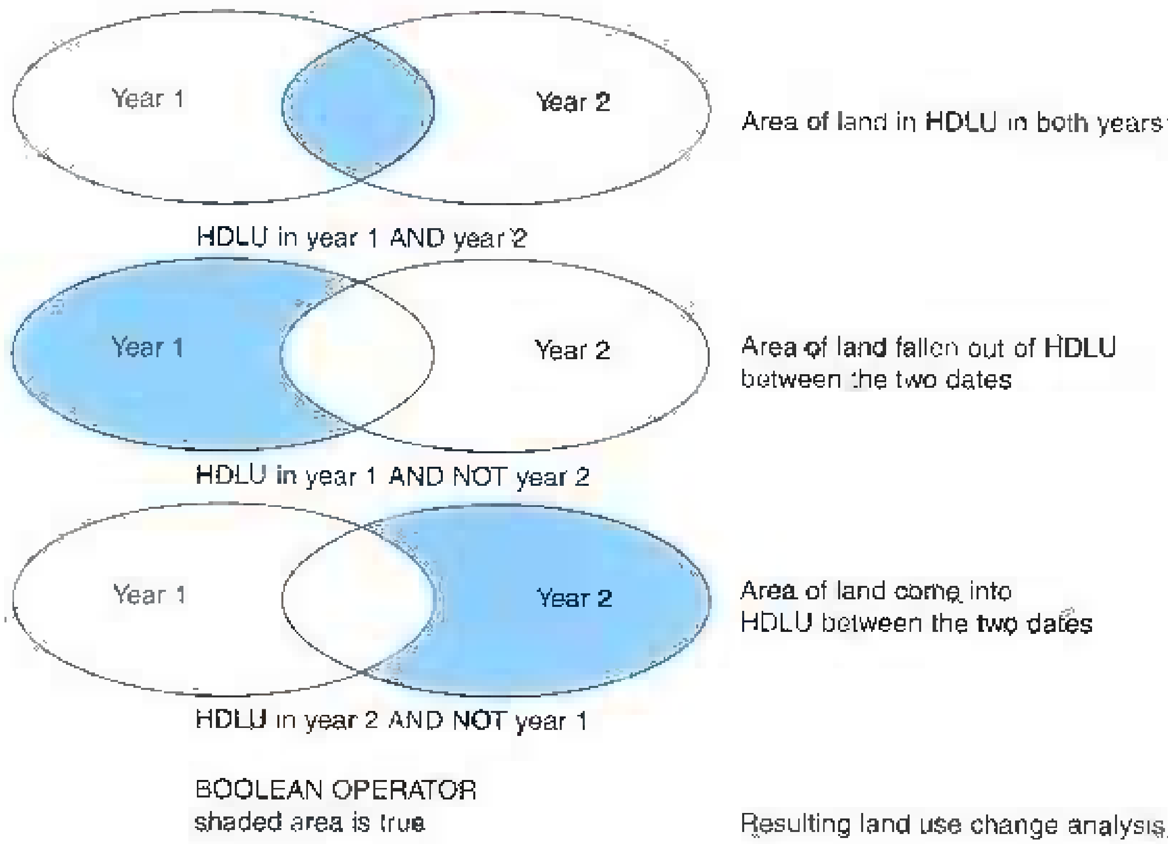

Figure 8 Boolean logic searching to determine land use changes between two dates

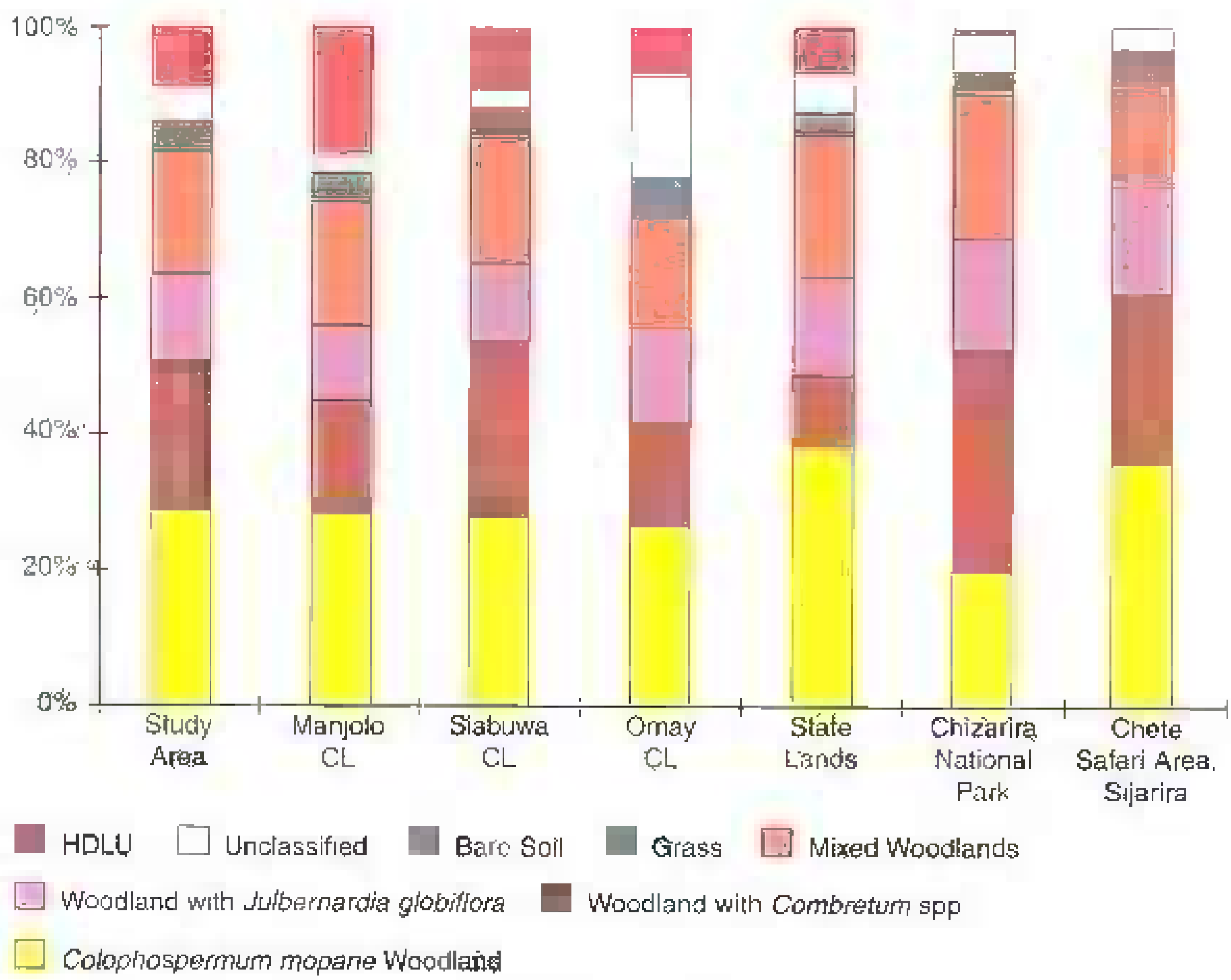

Figure 9 % of land cover by administrative unit, 1993

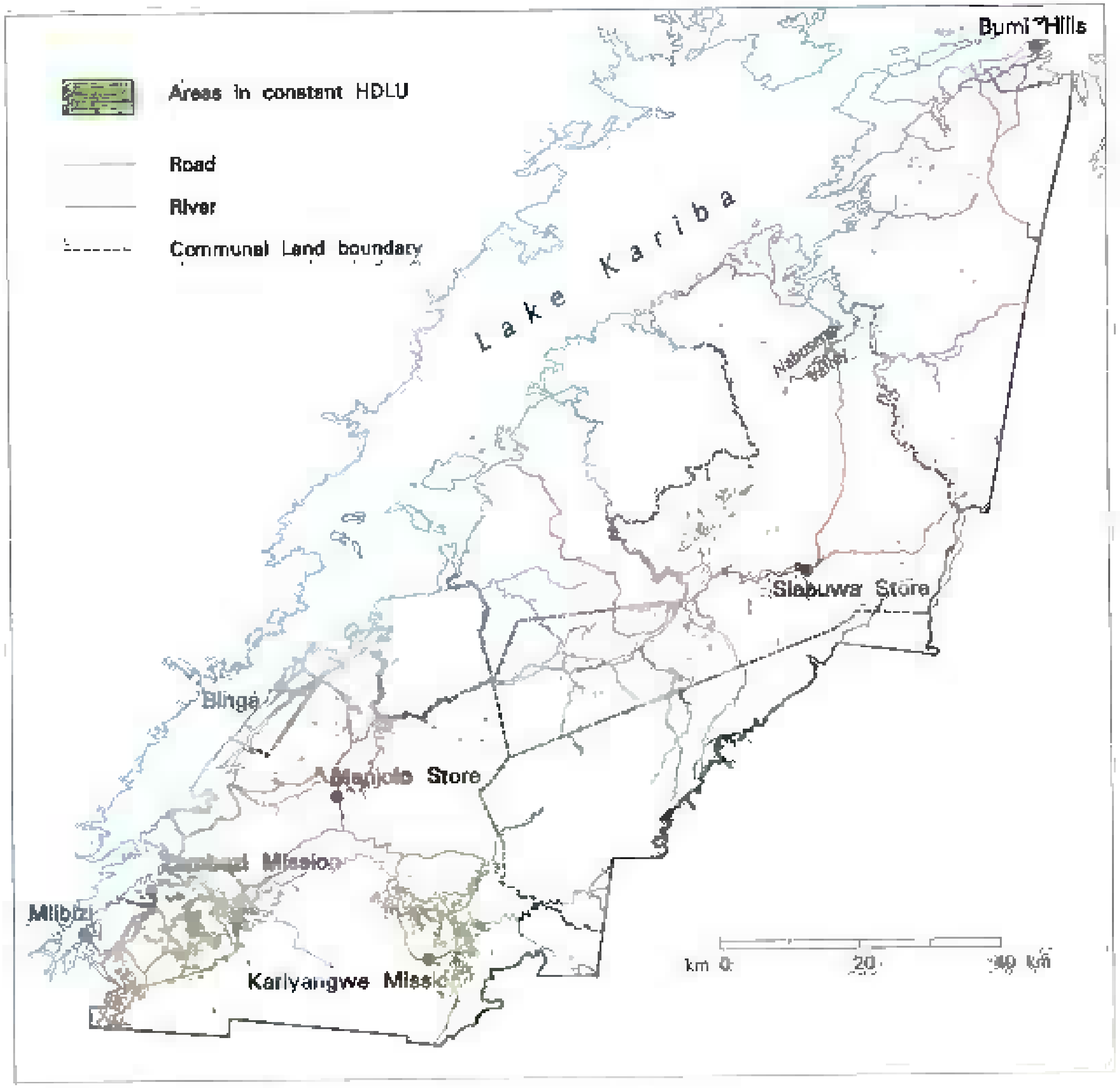

Figure 10 Areas in constant HDLU through the study area

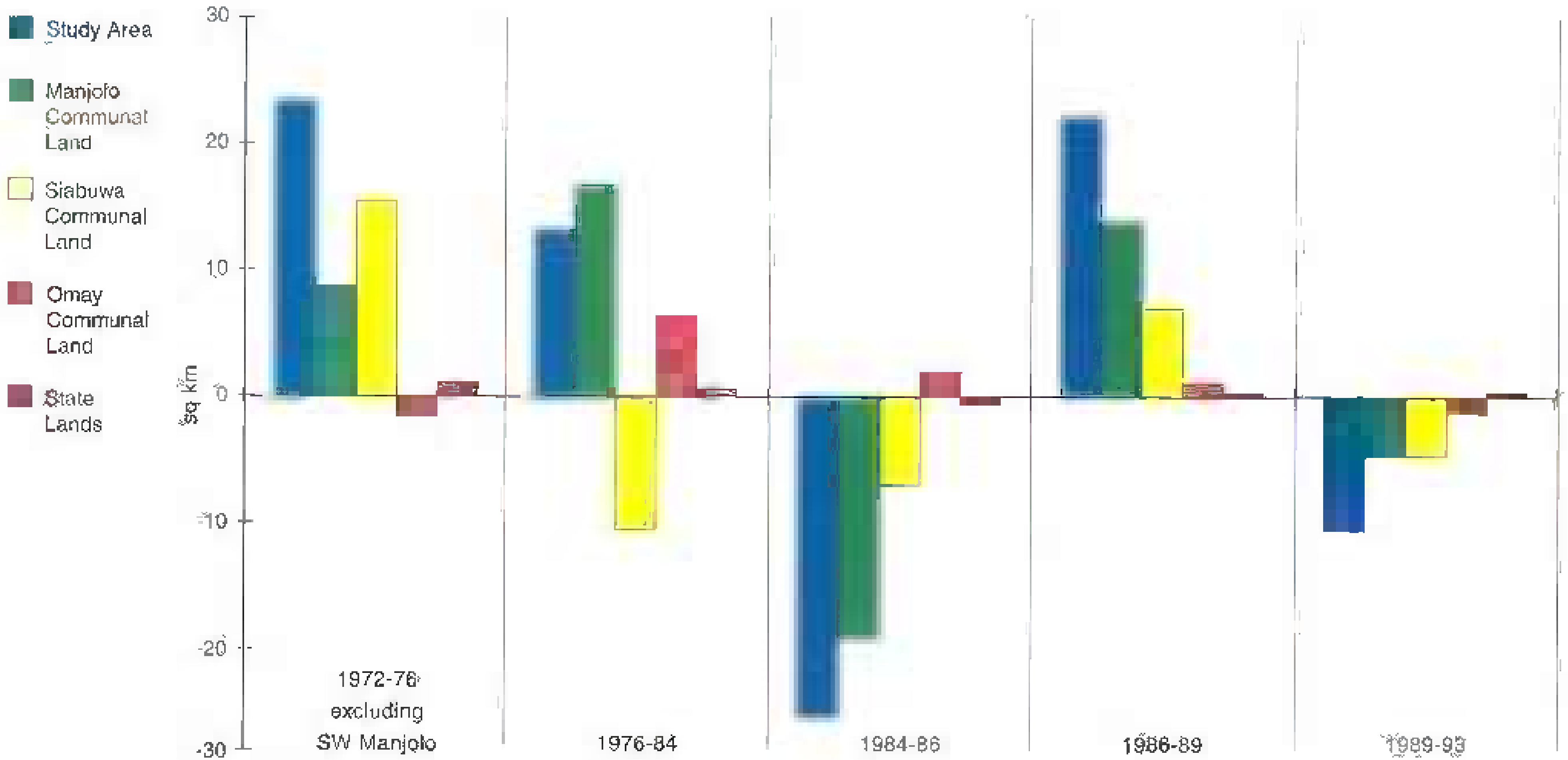

Figure 11 Net changes in HDLU per annum throughout the study area

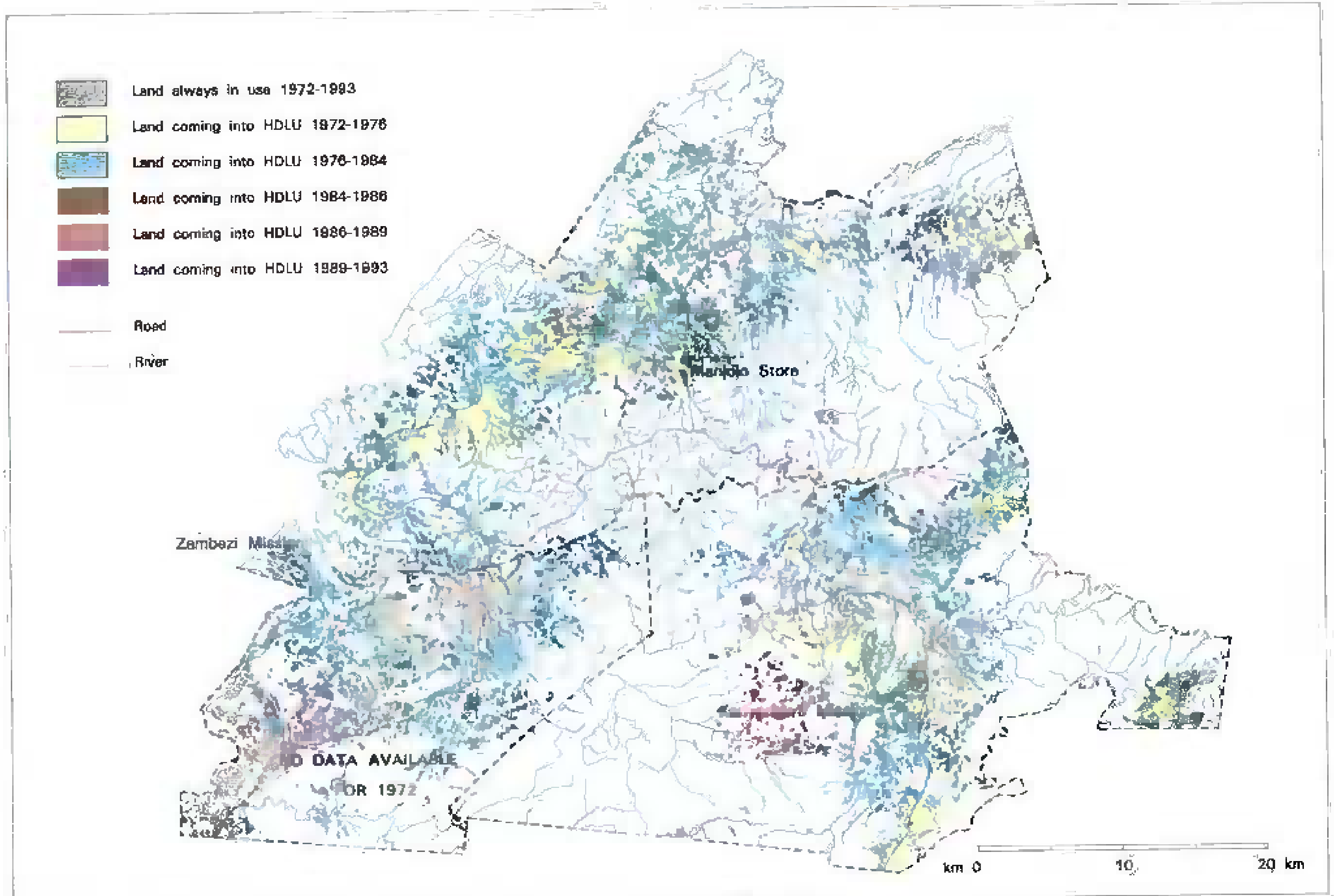

Figure 12 Expansion in HDLU in the Manjolo Communal Land

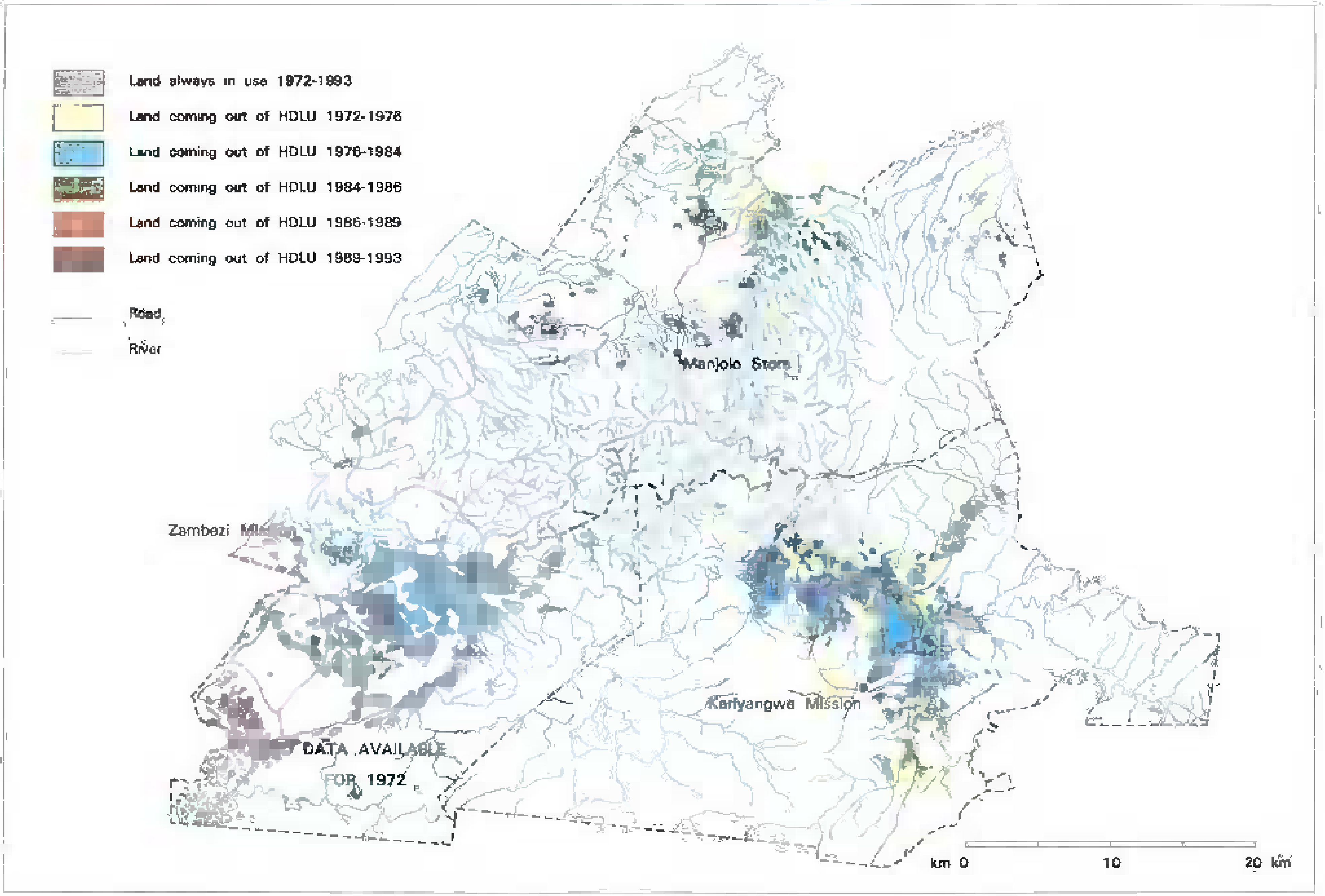

Figure 13 Land use decreases in Manjolo Communal Land

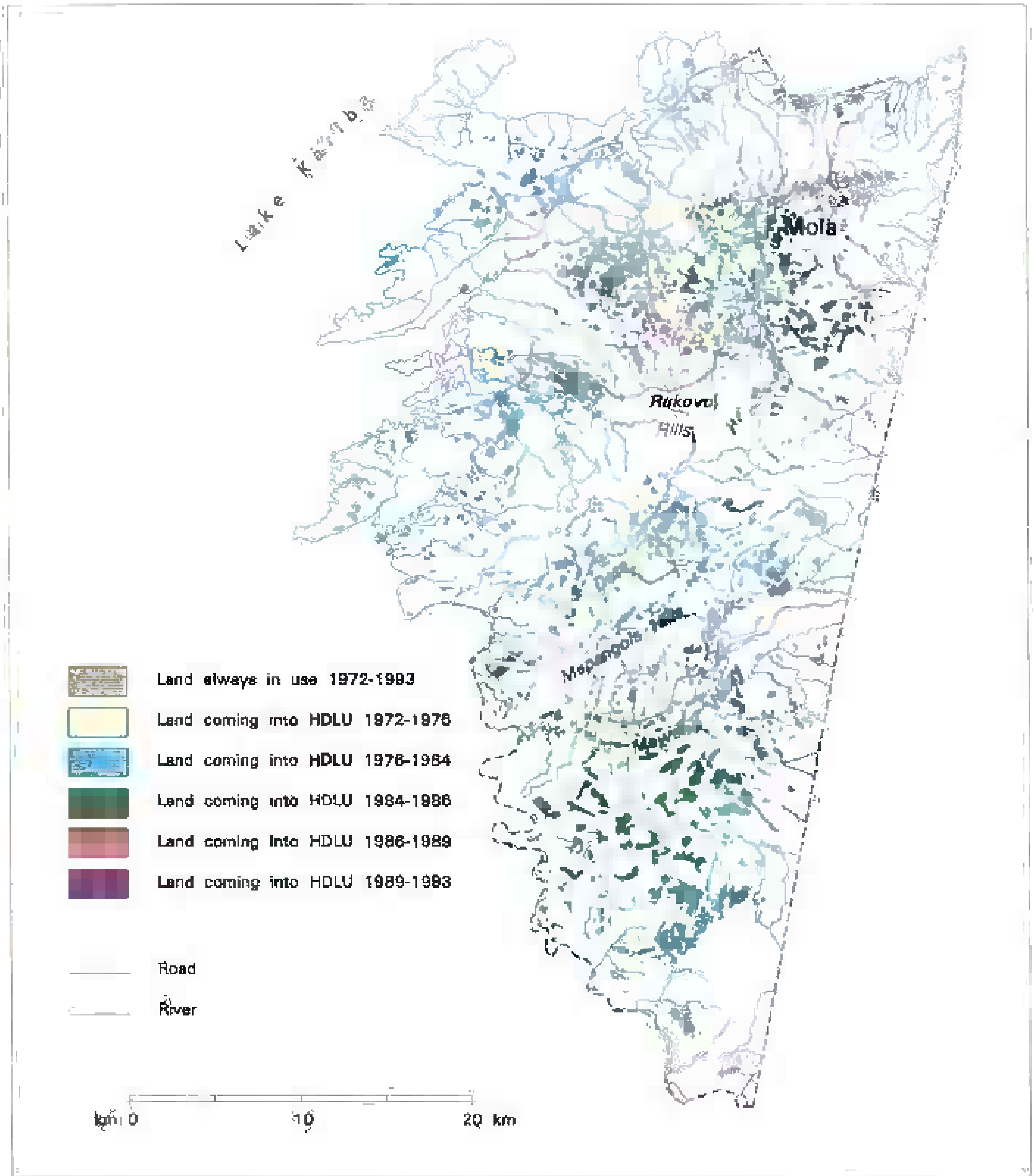

Figure 14 Expansion in HDLU in the Omay Communal Land

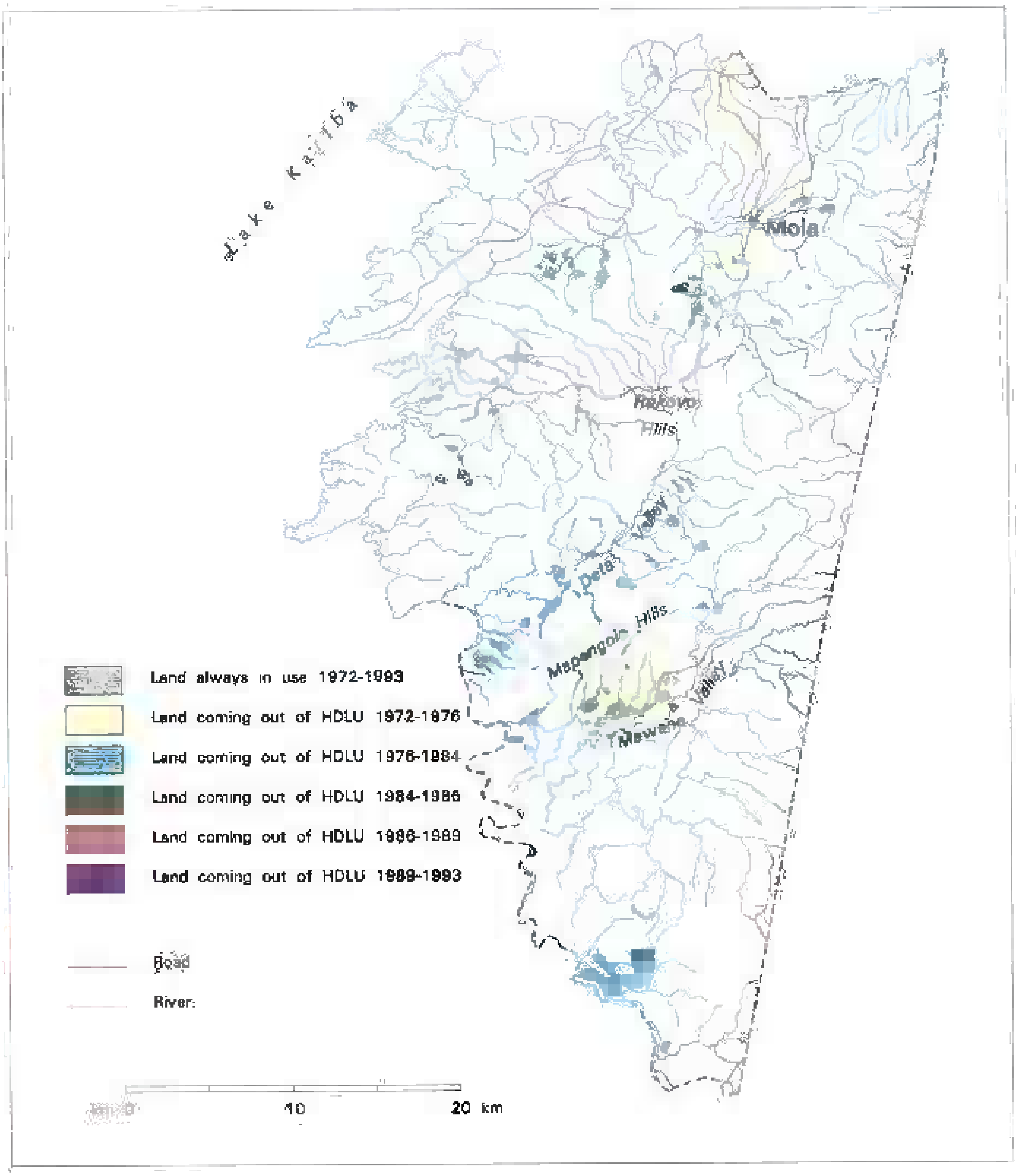

Figure 15 Land use decreases in Omay Communal Land

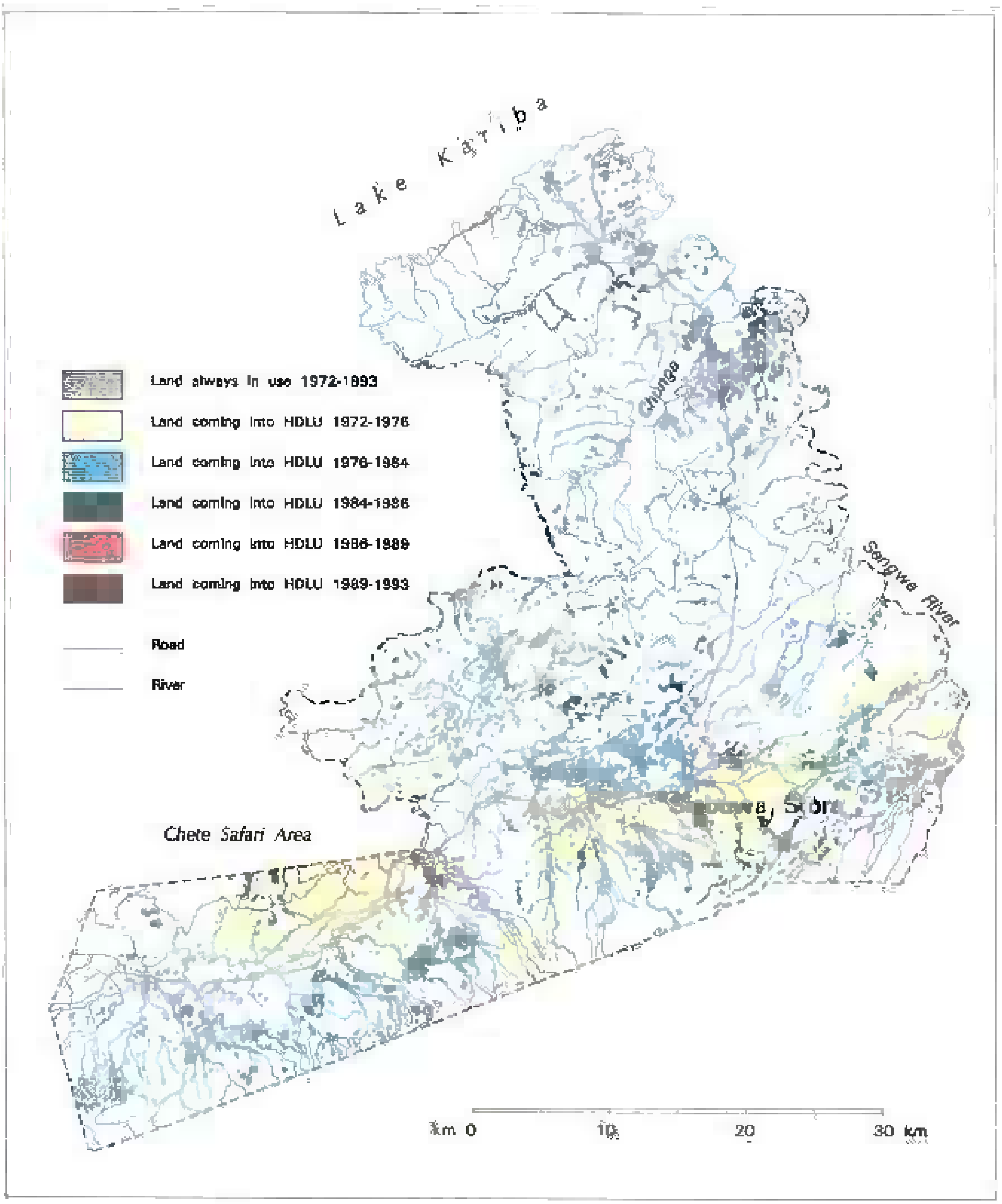

Figure 16 Expansion in HDLU in the Siabuwa Communal Land

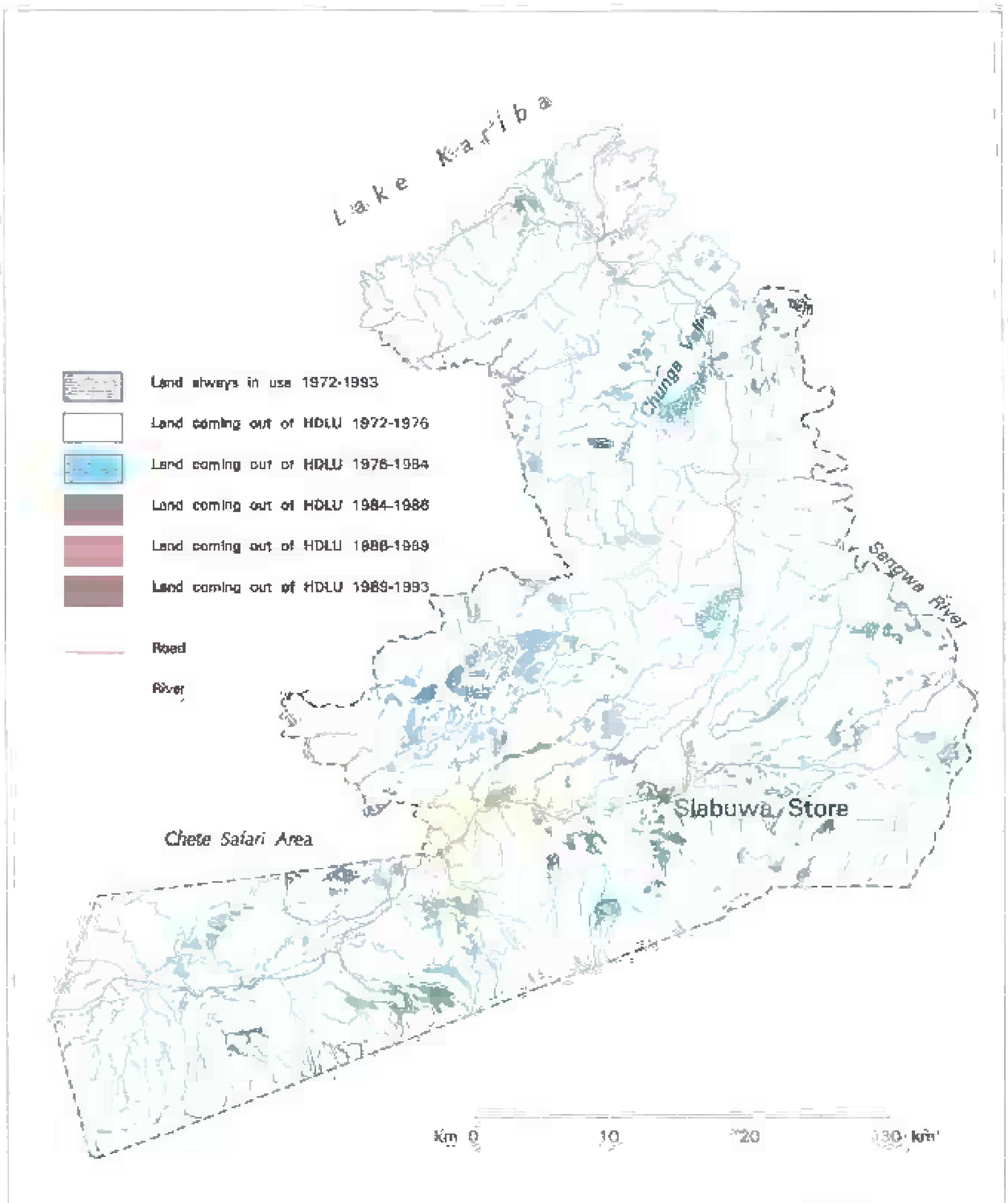

Figure 17 Land-use decreases in Siabuwa Communal Land

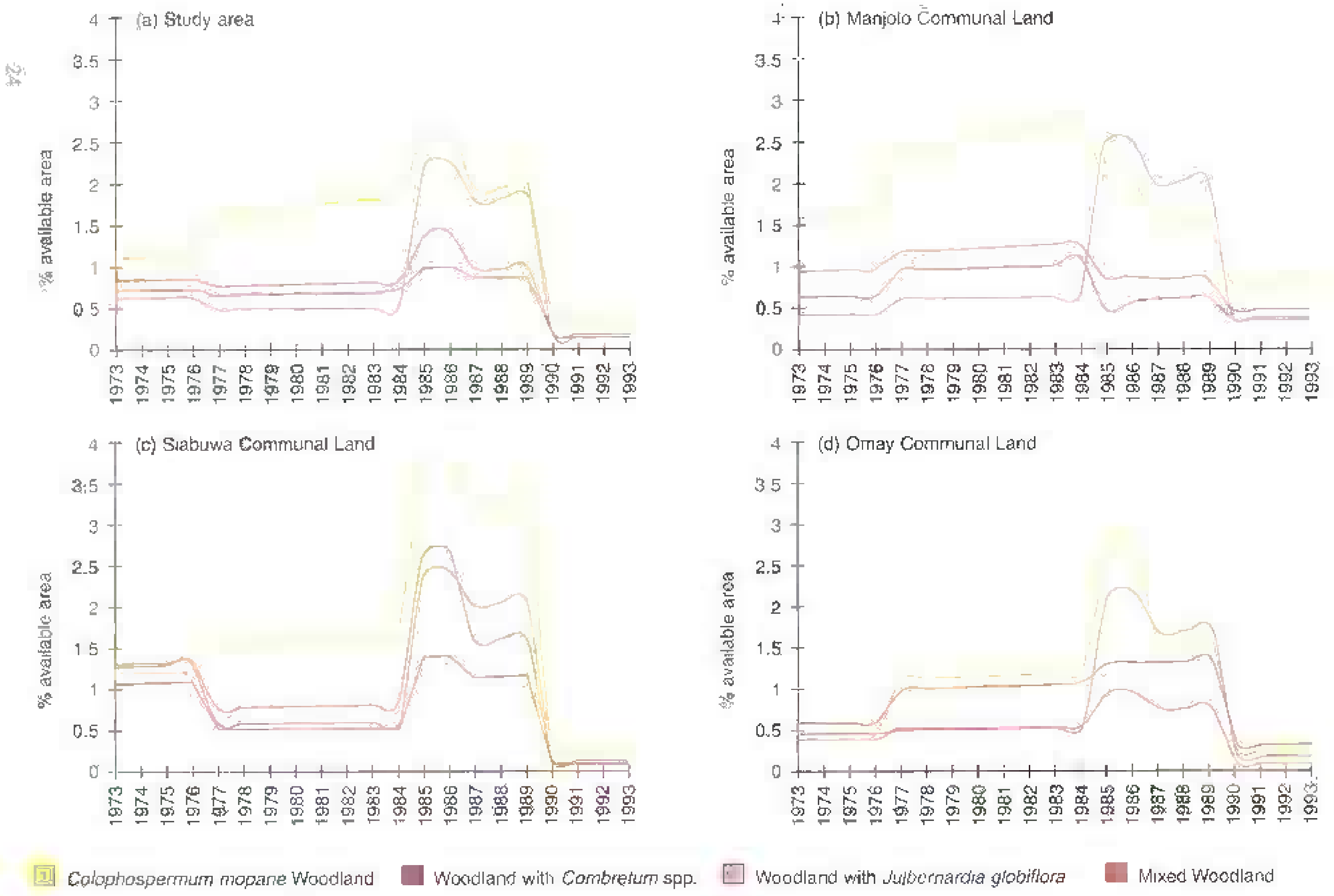

Figure 18 Percentage of woodland type lost to HDLU per annum in the study area and the Communal Lands

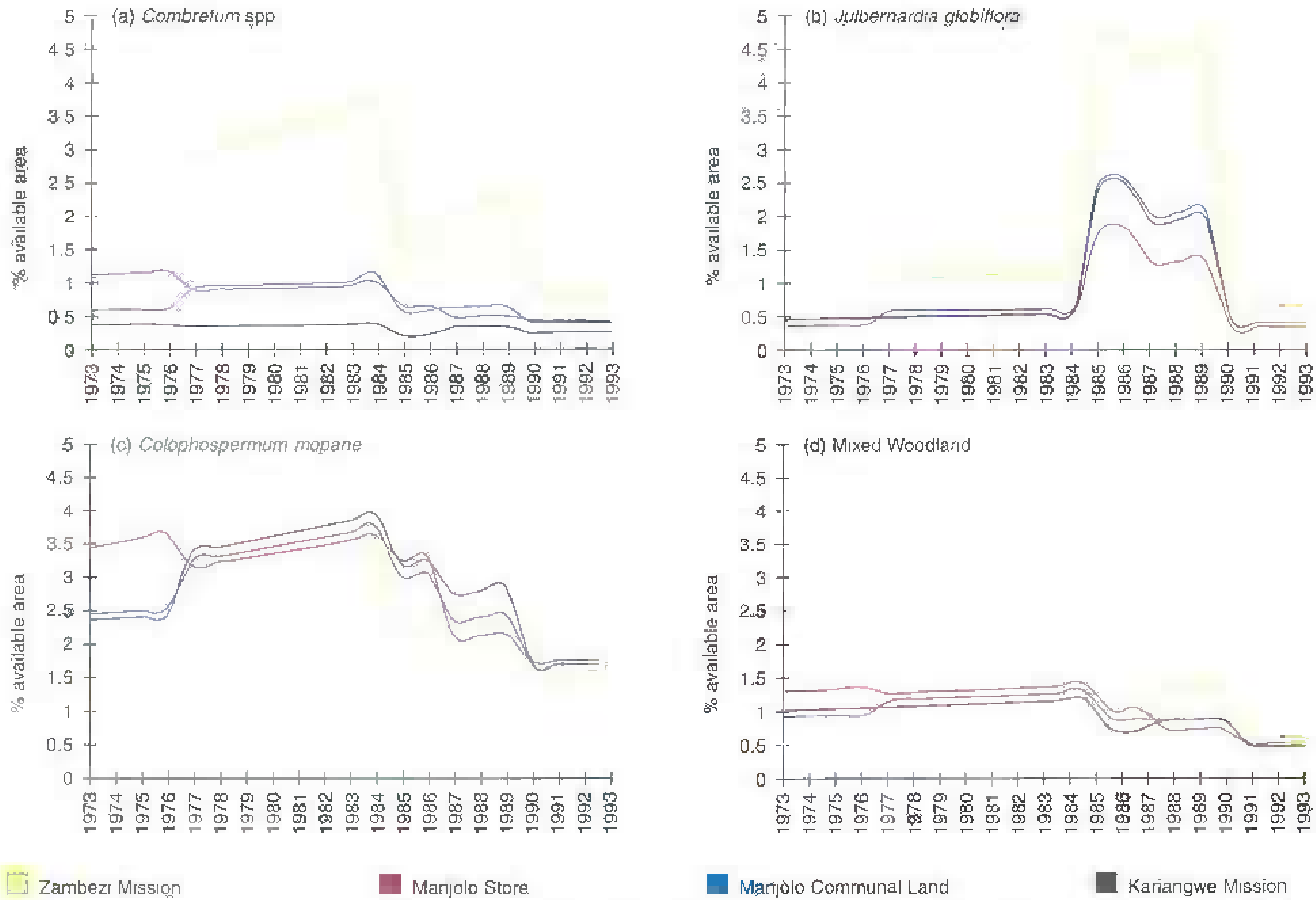

Figure 19 Percentage of woodland type lost to HDLU in Manjolo Communal Land (no data available for Zambezi Mission area before 1976)

areas on the 1976 image (in particular the southern Siabuwa Communal Land) were not entirely clear, although usable.

All imagery was registered to UTM Zone 35 using Clarke's 1866 Spheroid projection. The 1993 image was rectified to a 1982 1:250 000 topographical map (Harare Surveyor General) using a third order transformation. The image was resampled using the nearest neighbour method with an average root mean square (RMS) error of approximately 45 m. Earlier images were corrected to the 1993 image in order to minimize error between the images.

A baseline classification of the study area into 15 land-use and vegetation classes relied on separation of vegetation types with similar spectral responses according to parameters external to the satellite imagery classes (i.e. field surveys, information on geology, topography and administrative boundaries) (Pender and Rosenberg, 1995). For example, bare soils were classified into three groups (HDLU, fire-affected and unidentified origin) according to administrative unit, which indicated whether human activity was permitted in the area. Similarly, grasses were sub-divided according to their position in well watered valleys, round lakes and dams or if grass regrowth after burning could be detected. The automatic classification used in this study to determine changes in land cover over time, could not use this detailed classification procedure.

An early dry season Landsat TM image for May 1993 was used to classify land cover automatically. At this time of year, most areas of cultivation are bare ground or have a light cover of dried vegetation matter after harvest, with residual natural vegetation. Most of the spectral signatures are therefore derived from the residual stands of natural vegetation and are classified as such in the land cover map. Only the most heavily cleared cultivated areas are indicated on the image as totally bare ground. This is also the best time of year for maximum separation of *Colophospermum mopane* woodland from other woodland vegetation types as *C. mopane* retains its leaves during part of the dry season (Prince and Astle, 1986). A cluster analysis program (TWINSPAN) was used to group communities of tree and bush species identified at 204 field sites surveyed in 1993, in order to impose an impartial rigour into the classification. Grass and non-woody species were not differentiated in the 1993 field surveys and could not be included in the TWINSPAN analysis.

Image interpretation was conducted using Erdas Imagine software in a UNIX workstation environment. Although the vegetation was greener on the dry season 1993 image than it had been on the 1992 wet season image, underlying geology still significantly influenced spectral signatures. Using band 7, which is highly discriminant of substrate, an ISOCLASS unsupervised classification was carried out to highlight differences due to geology. The highlighted image was then divided into three masks corresponding to light, medium and dark substrates and these masks were used for the land cover classification. Water and shadow signatures were also masked out and were not included in the final classification. The mask areas were then applied to bands 3, 4, and 5 for classification into land cover types (Figure 5). Sites which were classified in the same vegetation type in both the TWINSPAN and manual interpretation of the 1992 image, were used as training sites in the supervised automatic classification of the 1993 image. Since the TWINSPAN classification included only woodland and bush cover, areas of bare soil and grass were defined from field classification only. Additional training sites were identified from areas on the image with the same spectral characteristics where necessary.

There were several spectral signatures possible on each mask for the same major cover type. *Colophospermum mopane* woodland, for example, showed different signatures according to tree height and canopy density, with five different signatures on the light substrate mask. Finally, 13 training signatures were defined for the light substrate mask and nine on both the medium and dark mask images. These signatures were combined into six classes on each mask and the masks were then joined together for the final classification.

Areas of HDLU (cultivation, settlement, grazed areas, airstrips, etc.) appear as white patches on a 3, 4, 5 band colour composite of an image. In the dry season, the shapes of fallow or uncropped fields are clearly visible (Figure 6). Since spectral signature conflicts occur with areas of naturally bare ground (rocky outcrops, mud or sand flats next to rivers, dams or the lakeshore), measurements of HDLU could not be resolved purely by automatic means, however, and a method of visual interpretation was adopted. A Sobel filter was applied to band 7, which provides good discrimination of bare soil against vegetation, and divided into six classes from strong edges to no edges. When this classification is displayed over band 3, sharp boundaries are conspicuous (Figure 7). The Sobel filter also identified shadow, topographical breaks, rivers and some roads, but these were ignored in the interpretation. Naturally occurring bare ground tended to have less sharply defined edges and a more irregular shape than fields and could be discounted. A false colour composite of bands 3, 4 and 5 was displayed next to the Sobel filter on band 3 and polygons of identified HDLU were digitized as an ARC/INFO GIS coverage using the Imagine-ARC/INFO live link facility.

A Sobel filter was also applied to Landsat TM imagery for 1989. This was overlaid on band 3 and displayed at the same time as a 3, 4, 5 band false colour composite with the 1993 digitized HDLU overlay. Differences between the HDLU in the two years were edited for additions and deletions to build up a digitized HDLU coverage for 1989. The process was then repeated using 1984 imagery.

Edge enhancement was not possible on the MSS images due to the typical streaking effect in MSS data. HDLU was identified using a band 4, 5, 6 false colour composite and the same editing technique was used. On the older Landsat images, image contrast was degraded, making the detection of HDLU more difficult. All the coverages were independently checked to optimize the accuracy of the interpretation,

The resulting HDLU layers were overlaid in ARC/INFO GIS and checked for registration. Sliver polygons arising from mis-registration were eliminated for areas less than 200 m^2.

DATA INTEGRATION

In order to analyse HDLU over time, the digitized layers for each image date were transferred to a GIS where they could be overlain with additional geographical data from a variety of sources (Table 2).

Each polygon of land identified as having been under HDLU at some time in the study period was coded in an attribute table for each analysis date as Y if HDLU had been detected at that date and N if not detected. Boolean logic was then used to identify areas of land in HDLU at the time of each image, as well as for evaluating increases and decreases in HDLU between successive dates (Figure 8). The resulting datasets therefore contained available HDLU polygons and their areas.

Table 2 Geographical information system (GIS) coverages

Data layer	Source	Scale
(a) The whole study area		
Vegetation classes 1992	TM[1] imagery 19.2.92	1:250 000
Land cover and land use 1993	TM[2] imagery 28.5.93	1:50 000
Land use 1989	TM imagery 20.7.89	1:50 000
Land use 1986	MSS imagery 12.7.86	1:100 000
Land use 1984	TM imagery 22.7.84	1:50 000
Land use 1976	MSS imagery 13.8.76	1:100 000
Land use 1972	MSS imagery 13.9.72	1:100 000
Geology	Zimbabwe Geological Survey	1:1 million
Drainage	ZSG[3] 1982 ed	1:250 000
Roads	ILRI[4] dataset	1:250 000
Administrative boundaries	ZSG 1974 ed.	1:500 000
Settlement 1963	ZSG 1982 ed	1:250 000
Field survey sites	Fixed by GPS[5],	
Field routes	Based on roads and GPS	
Areas covered by ground spray operations 1970–90	Lovemore (1995) RTTCP[6]	1:250 000
Areas covered by aerial spray operations 1970–90	Lovemore (1995) RTTCP[6]	1:250 000
Areas covered by target trap control operations 1970–90	Lovemore (1995) RTTCP[6]	1:250 000
Annual limit of tsetse fly infestation	Lovemore (1995) RTTCP	1:250 000
Game fences	Lovemore (1995) RTTCP	1:250 000
Cattle fences	Lovemore (1995) RTTCP	1:250 000
Bovine trypanosomiasis distribution	Lovemore (1995) RTTCP	points
Prophylaxis applications	Lovemore (1995) RTTCP	points
Livestock numbers 1983—present	P Gamble DVS[7] (personal communication)	ward level
(b) Manjolo Communal Lands		
Terrain units	Aerial photography 1990	1:25 000
Human land use	Aerial photography 1990	1:25 000
50 m contours	ZSG 1977	1:100 000
(c) Chizarira National Park		
Landforms	Aerial photography 1990	1:25 000

1 TM Thematic Mapper
2 MSS Multi-Spectral Scanner
3 ZGS Zimbabwe Surveyor General
4 ILRI International Livestock Research Institute
5 GPS Global Positioning System
6 RTTCP Regional Tsetse and Trypanosomiasis Control Programme
7 DVS Department of Veterinary Services

Results

CHANGES IN LAND COVER

Seven land cover classes were derived from the analysis of the May 1993 Landsat TM image—four woodland groups, two relating to grass and naturally occurring bare soil and a HDLU class; 5% of the area was unclassified due to cloud cover and shadow effects (Table 3). The land cover classes are described below.

(a) *Colophospermum mopane* Woodland. Single dominance *Colophospermum mopane* woodland occurs on gently undulating land and along valley bottoms, mainly below 1100 m, although in contrast to previous studies (e.g. Cole, 1986), this vegetation class was also found at higher altitudes. On Karoo Sandstones in the Siabuwa Communal Land, the eastern parts of the Chete Safari Area and the whole of the Sijarira Forest, this woodland occurs in a mosaic of alternating single dominance with *Julbernardia globiflora*. Mopane woodland ranges from low scrub to tall cathedral mopane with a sparse under-canopy. This class is spectrally distinct from all other classes apart from the edges of the mopane stands.

(b) Woodland with *Julbernardia globiflora*. An open mixed woodland in which *Julbernardia globiflora* is the most common species, together with *Burkea africana, Diplorhyncus condylocarpon, Crossopteryx febrifuga* and *Pseudolachnostylis maprouneifolia*. There is also a shrub layer, with *Baphia massiensis* and *Combretum* spp. On higher ground this class is miombo woodland, dominated by *Brachystegia boehmii* and *Julbernardia globiflora*, while on the Karoo Sandstones, it occurs in a mosaic of alternating single dominance with *Colophospermum mopane* (see (a) above). There is some spectral confusion on the image with classes (c) (mixed woodland) and (d) (woodlands with *Combretum* spp.)

Table 3 Land cover in the study area in 1993 from Landsat TM imagery

Land cover type	Area (km^2)	% of area
a. *Colophospermum mopane* woodland	2368	28.8
b. Woodland with *Julbernardia globiflora*	1092	13.2
c. Mixed woodland	1481	17.9
d. Woodland with *Combretum* spp.	1770	21.4
e. Grass	33	0.4
f. Bare soil	327	3.9
g. HDLU	764	9.1
Unclassified	442	5.4

(c) Mixed Woodland. This class comprises types of woodland that could not be spectrally separated or defined by dominant species composition. It includes riverine woodland, often not more than 30 m wide, large areas of dense woodland on undulating hills in the northern part of Manjolo Communal Land and mixed woodlands on escarpments. There is spectral confusion on the image between this class and classes (d) (woodlands with *Combretum* spp.) and (e) (well watered grasses bordering rivers).

(d) Woodland with *Combretum* spp. Woodland with a dense shrub layer dominated by *Combretum* spp., often with *Guibourtia conjugata* and occurring on Kalahari Sands in the southwest of the study area, along escarpment tops above mixed woodland and in dense thickets close to human cultivation.

(e) Grass. Areas of well watered grassland close to rivers, dams or lakes and irrigated areas.

(f) Bare Soil. This class includes naturally occurring bare rock and soil and bare soil exposed by changing water levels in lakes and dams.

(g) Human-Dominated Land Use. This class includes built-up areas, such as the town of Binga, airstrips, rural settlement and grazed and cultivated land. In rural areas, settlement cannot be distinguished from the surrounding cultivated areas as most settlement units comprise individual extended families living close to their fields (Pender and Rosenberg, 1995).

The extent and location of each simplified natural vegetation class broadly corresponds to the equivalent group identified in the study area by previous surveys (Pender and Rosenberg, 1995; Timberlake *et al.*, 1993). About 50% of the study area is covered by *Colophospermum mopane* woodland and woodland with *Combretum* spp. (Table 3), the former comprising a broad southwest to northeast oriented belt, mainly to the north of the Chizarira Escarpment and the latter occurring in distinct patches on deposits of Kalahari Sand in Manjolo Communal Land, Chete Safari Area, Sijarira Forest Area and in the Chizarira National Park. *Colophospermum mopane* woodlands are the most extensive natural vegetation cover (27–39%) (Figure 9) in all the Communal, State and Reserved Lands with the exception of the Chizarira National Park where the proportions of mopane and mixed woodlands are similar (20% and 21%) (Figure 9), and woodlands with *Combretum* spp. are the most extensive (33%). Mixed woodlands comprise nearly 18% of the natural vegetation cover and are found on low hills near Binga and as

Table 4 Percentage of land in HDLU in the Communal Lands and State Lands

Year	Manjolo Communal Lands	Siabuwa Communal Lands	Omay Communal Lands	State Land	Study area
1972	7.73[1]	10.60	4.06	0.55[2]	5.66[1]
1976	14.13	13.77	3.52	3.36	8.26
1984	19.61	9.90	6.93	6.22	9.46
1986	17.82	9.26	7.25	5.27	8.82
1989	19.76	10.29	7.50	5.81	9.69
1993	18.87	9.31	7.08	6.78	9.13
Land always in HDLU	4.68	1.46	0.27	1.82	1.78

excluding Zambezi Mission
excluding Mlibizi

part of riverine complexes along most watercourses, while broad belts of woodlands with *Julbernardia globiflora* are found in Chizarira National Park, both above and along the escarpment, and in parts of the northern Siabuwa Communal Land, Chete Safari Area and Sijarira Forest Area.

Bare ground covers 3.9% of the study area, principally around the lakeshore where changing water levels expose naturally occurring bare soil and rock. Only 0.4% of the study area is classed as grassland (Table 3), which is mainly confined to vleis in the Chizarira National Park, restricted patches around lakes and dams and isolated open spaces.

Within the broad-scale natural vegetation pattern, a complex mosaic of different vegetation classes also occurs, particularly in northern Siabuwa Communal Land, Chete Safari Area and Sijarira Forest Area where the terrain is deeply dissected into the sandstone and siltstone substrate complex (Pender and Rosenberg, 1995).

On the 1993 imagery, HDLU comprised 9.1% of the land area although only 1.8% of the total land in the study area was consistently under HDLU between 1972 and 1993 (Table 4). The proportion of land constantly in HDLU is always higher in the Communal Lands than in the State Lands, and more permanent HDLU occurs in the Manjolo Communal Land (4.7%) than elsewhere (Table 4). No HDLU could be identified in the Reserve Lands except in the Chizarira National Park where there is limited settlement by park staff and where some settlement associated with the Kariyangwe Basin extends into the eastern reaches of the park.

Five core areas of permanent HDLU could be identified: the Lwizilukulu valley near Siabuwa Store in the Siabuwa Communal Land, the Nabusenga valley in the Omay Communal Land and three areas in the Manjolo Communal Land—the area surrounding Manjolo Store (west of Binga), the Zambezi Mission area (between Mlibizi and Cockcroft Bridge), and the Kariyangwe Mission area in the middle Sebungwe valley (Figure 10). Scattered permanent HDLU also occurs along the footslopes bordering the northern edge of the Chizarira National Park. The core HDLU areas are more distinct in Manjolo Communal Land where there are large areas of farming land on gently undulating ground, while further north, the core HDLU areas are situated on small patches of favourable land surrounded by incised terrain (Figure 10).

CHANGES IN HUMAN-DOMINATED LAND USE

The proportion of land under HDLU increased from 5.7% to 9.5% between 1972 and 1984, and reached a maximum of 9.7% in 1989, after a decrease in 1986. The proportion slightly decreased again by 1993 (Table 4). The largest net increase in HDLU (26.2 km^2 per annum) occurred between 1972 and 1976, and the largest net decrease (27.5 km^2 per annum) between 1984 and 1986.

Within the study area, the pattern of net decreases and increases in HDLU over time is more complex (Figure 11). There was a net increase in HDLU in all the Communal and State Lands only between 1986 and 1989, whereas at other times, one of the Communal Land areas or the State Lands exhibited changes in HDLU contrary to the general trend (Figure 11). The largest changes occurred in the Manjolo Communal Land where the proportion of HDLU was highest, and the smallest in the State Lands and Omay

Communal Land (Figure 11). Even at this level of analysis, however, the figures for net increase and decrease in HDLU hide an underlying pattern of dynamic spatial and temporal change. For example, the Karyiangwe Basin in the Manjolo Communal Land covers an area of 1678 km^2 along the middle reaches of the Sebungwe river. The main area of settlement is almost completely surrounded by low escarpments, which until recently confined settlement to the basin (Figure 12). Only 40 km^2 (2.4%) of the total area of the Kariyangwe Basin was continuously under HDLU between 1972 and 1993, although, the actual area being used at any one time varied between 123.8 (1972) and 155 km^2 (1989). Most of the HDLU is concentrated in the basin (Figure 12). Between 1972 and 1993, there was a net increase in HDLU in the Karyiangwe Basin of only 25 km^2, the most pronounced net increases occurring between 1976 and 1984 and between 1986 and 1989 (Table 5). In the remaining periods, the area under HDLU appears relatively stable (1972–76) or shows a net decrease (1984–86 and 1989–93) (Table 5). The net change in HDLU of 0.2 km^2 during one 'stable' period from 1972 to 1976, however, does not reflect the fact that approximately 63 km^2 of land went into and came out of HDLU during this time (Table 5). Similarly, although there was only a small change in the total area under HDLU in the period between 1989 and 1993, there was a significant increase in HDLU for the first time above the escarpments surrounding the basin, reflecting a move away from settlement on the preferred Permian (Karoo) glacial deposits in the basin to the Triassic (Karoo) grits of the escarpment (Figures 12 and 13).

Between 3.5% and 7.5% of the land area in the Omay Communal Land was under HDLU during the study period, although less than 0.3% of the HDLU was permanent (Table 4). Increases and decreases in HDLU were correspondingly small between 1972 and 1993 (Figure 14), reflecting the highly fragmented pattern of settlement in a dissected terrain. Increases in HDLU were most pronounced between 1976 and 1984 (Figure 11) and occurred as expansions from core HDLU areas such as Mola and along the Mawene and Deta valleys (Figure 14). Some new discrete areas of land (e.g. north of the Ruokovo Hills) also came into HDLU during the study period (Figure 14). In contrast, by 1993 HDLU had almost completely disappeared from the Deta Valley (Figure 15).

The pattern of HDLU change in Siabuwa Communal Land is a combination of those seen in the Manjolo and Omay Communal Lands. The proportion of land under HDLU ranged from 9.26% in 1986 to 13.8% in 1976 (Table 4) with a core area of 1.5% consistent HDLU focused principally around Siabuwa store, the Chunga valley and the western edge of the Communal Land adjacent to Chete Safari Area (Table 4 and Figures 16 and

Table 5 Changes in human-dominated land use (HDLU) in the Kariyangwe Basin

	Land brought into HDLU (km^2)		Land taken out of HDLU (km^2)	
Period	per period	(av per year)	per period	(av per year)
1972–76	31.6	(7.9)	31.8	(7.95)
1976–84	84	(10.5)	59.1	(7.38)
1984–86	16.6	(8.3)	25.3	(12.65)
1986–89	22.8	(7.6)	7.5	(2.5)
1989–93	16.6	(4.15)	23.1	(5.78)

17). The largest net decrease in HDLU occurred between 1984 and 1986, followed by a substantial net increase between 1986 and 1989 (Figure 11). The southern part of the Communal Land comprises a substantial core area of HDLU centred on the Siabuwa Store and changes in HDLU have been focused along the major river valleys and the roads (Figures 16 and 17). In the northern part of the Siabuwa Communal Land, changes in HDLU have occurred predominantly around fragmented and ill-defined core areas in dissected terrain, a similar pattern to that in the Omay Communal Land (compare Figures 14 and 15 with Figures 16 and 17). Exceptions to this can be seen at the mouth of the Sengwa river and the adjacent Lake Kariba shore and in the Chunga valley, where HDLU changes have occurred around well-defined core HDLU areas (Figures 16 and 17).

CHANGES IN HUMAN-DOMINATED LAND USE IN RELATION TO NATURAL VEGETATION COVER IN THE COMMUNAL LANDS

The amount of land taken into HDLU in the Communal Lands differs for each of the four woodland classes. Over the whole study area, proportionally more *Colophospermum mopane* woodland is lost than any other woodland class, particularly before 1986, after which similar proportions of *C. mopane* woodland and woodland with *Julbernardia globiflora* are lost (Figure 18a). There were differences however, between the three Communal Lands. In Manjolo Communal Land proportionally more mopane was lost before 1986, whereas in Siabuwa Communal Land, the highest mopane loss was in the late 1980s. Similar proportions of *C. mopane* woodland and woodland with *J. globiflora* were lost during the study period in the Omay Communal Land (Figure 18b,c,d). In the study area, losses in all the woodland classes were proportionally greater in the late 1980s than previously, while the lowest rates of loss were in the 1990s (Figure 18). A similar pattern was found in the Siabuwa and Omay Communal Lands, but in Manjolo Communal Land only *J. globiflora* woodlands followed this trend (Figure 19) There are also pronounced local differences in the percentage loss of different woodland classes over time and these differences are most pronounced in the Manjolo Communal Land where the overall pattern of annual losses in mopane, mixed woodland and woodland with *J. globiflora* is similar. However, proportionally higher losses in *Combretum* spp. occurred before 1984 and higher proportions of *J. globiflora* were lost in the late 1980s in the extensively settled area around the Zambezi Mission than elsewhere in Manjolo Communal Land.

CHANGES IN HUMAN-DOMINATED LAND USE IN RELATION TO TSETSE CONTROL OPERATIONS

The history of tsetse control varies from south to north throughout the study period as the limit of tsetse occurrence was pushed northward (Figure 3). There have been three distinct periods of tsetse control in the study region: ground spraying before Independence in 1980; intensive aerial spraying with supporting ground spraying in the period 1982 to 1985; and finally, target barrier control in the north since 1988 (Figure 3). Changes in HDLU in three areas characterized by one of these periods of control, have been studied in detail to determine the relationship with the extent and frequency of control operations.

Before 1980, tsetse control operations concentrated on settled areas in the Manjolo Communal Land, especially in the Manjolo Store area (Lovemore, 1995). HDLU doubled between 1972 and 1976 and between 1976 and 1984 in the Manjolo Store area, but thereafter, remained relatively stable (Table 6). These expansions occurred at the same time as, or immediately after tsetse control (Figure 3).

Control in the central part of the study area (i.e. the southern part of the Siabuwa Communal Land) took place between 1982 and 1985, although limited control continued on the northern fringes up until 1990 (Figure 3). More land was in HDLU in the 1970s in southern Siabuwa before control operations started. From 1984 there has been very little change in the percentage of land under HDLU in this area (Table 6).

In 1993, the southern limit of tsetse occurrence ran through Omay Communal Land at about 17°10'S, crossing the shore of Lake Kariba west of the Bumi Hills. No tsetse control occurred in the Omay Communal Land before 1985. The land to the south of the Bumi Hills is protected against reinvasion by a target barrier and selective ground spraying occurs inside the barrier to reduce the numbers of tsetse. HDLU in the Omay Communal Land appears to have been expanding and contracting irrespective of the timing and extent of tsetse control, with a doubling of HDLU between 1976 and 1984 and a relatively stable HDLU area subsequently (Table 4).

Table 6 Percentage of land in HDLU in the Manjolo Store area of Manjolo Communal Land and in the southern Siabuwa Communal Land

Year	Manjolo Store area	Southern Siabuwa Communal Land
1972	5.78	15.14
1976	9.60	16.75
1984	17.36	12.79
1986	15.38	10.75
1989	17.12	13.69
1993	16.46	12.59

Conclusions

The Communal Areas of Zimbabwe contain about 57% of the country's population and are characterized by increasing pressure from over-grazing, agricultural expansion and fuelwood collection (Gondo and Traub, 1993; Government of the Republic of Zimbabwe, 1992). At the same time, there is insufficient information concerning the extent and condition of the vegetation resources to support decisions on improved management, conservation and sustained utilization. In this study, Landsat MSS and TM data have been used to estimate changes in HDLU in relation to natural vegetation cover and tsetse control operations over a 20-year period in an area adjacent to Lake Kariba. Archived imagery, combined with other datasets in a GIS, enabled spatial analysis of land use change over five study periods between 1972 and 1993, even though the earlier imagery was quite degraded and difficult to interpret.

Land use change in this part of the Zambezi Valley is not a straightforward progression from a state of virgin land to one of extensive HDLU in response to increasing population pressure. There are simultaneous expansions and contractions of land use on many fronts and the pattern shows a highly dynamic process of change occurring beneath a picture of relative stability. Although only 1.8% of the total land cover was permanently under HDLU throughout the study, the proportion of HDLU ranged from 5.7% to 9.7%. When considered as a whole, there has been a fairly steady increase in the proportion of land under HDLU in the study area, with periods of expansion between 1972 and 1976, 1976 to 1984, and again between 1986 and 1989 interspersed with a periods of marked contraction (1984 to 1986) or little change (1989 to 1993). There are evident differences in the spatial and temporal variation of HDLU between the three Communal Land areas and the State Lands, with only one period between 1986 and 1989, in which all the Communal and State Lands showed net increases in HDLU. Within the Communal Lands, the most extensive expansions and contractions in HDLU tended to occur in the more densely populated Manjolo Communal Land and the smallest, in the Omay Communal Land where settlement is more highly fragmented.

Overall, similar proportions of the four woodland vegetation classes in the study area have been affected by HDLU change, although there are local variations in the extent to which different woodlands have been affected, with, for example, a high proportion of woodland with *Combretum* spp. being lost to HDLU in the Zambezi Mission area of the Manjolo Communal Land. However, the largest areas of natural vegetation lost to HDLU are in the *Colophospermum mopane* woodland and when these areas are abandoned, the vegetation tends to revert to either mixed woodland or a scrubland of predominantly *Combretum* spp., suggesting that the loss of mopane woodland is irreversible over a 20-year period at least.

There is little evidence of a direct relationship between the spatial and temporal patterns of HDLU change and either livestock numbers and composition or the frequency and extent of tsetse control operations, although the dataset for the former is very incomplete. Broad-scale changes in HDLU and higher rates of woodland vegetation loss may be attributed to increased political stability after Independence (1980), while net decreases or little change during and after drought (1981–84 and 1989–92) may be due to lack of confidence to plant after a failed harvest or because seed material is no longer available. Due to the unavailability of suitable satellite imagery, it was not possible to select dates for analysis which coincided more precisely with, for example, periods of drought, the start of improved security, the introduction of resettlement areas and the start and finish of tsetse control campaigns.

The validity of the results presented here depends on how well the land cover can be identified and classified from satellite imagery and how accurately changes in land use can be estimated from a time-series of images. Classification accuracy tends to decrease with time and the most accurate results from the satellite classification are likely to be for the May 1993 image since field work was carried out in the following month. Errors arose from geo-correction and from the varying quality of satellite data used, particularly the poor contrast enhancements from scanned 1970s imagery, which reduced the degree of separation between bare ground and vegetation. Although the Sobel filter aided identification of 'hard boundaries' between HDLU and natural vegetation, in areas with sharp natural boundaries (e.g. rocky outcrops, edges of fire scars), an over-estimation of HDLU was possible, while recent fire scars may have obscured areas which were dominated by human land use.

Although the results must be treated with caution, they show that in western Zimbabwe at least, changes in land use over time can differ markedly between adjacent Communal Areas and that tsetse control is probably only one component in a complex framework of factors which might influence agricultural development in an area. Monitoring and evaluation of the socio-economic aspects of land use change in tsetse infested and cleared areas should be a prerequisite for planning future tsetse control operations in Zimbabwe in particular and in the tsetse-affected areas throughout Africa.

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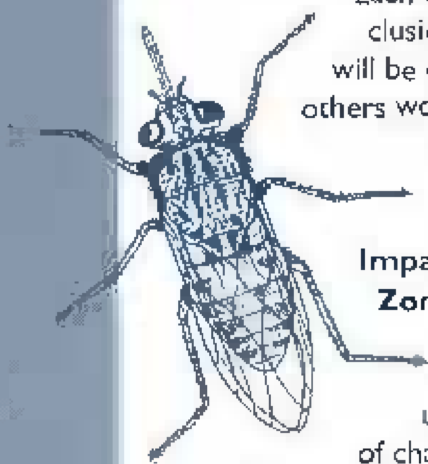

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This publication will be of interest to scientists, planners and resource managers, and all those interested in the agricultural development of this area of Zimbabwe.