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Impact of tsetse control on land use in the semi-arid zone of Zimbabwe. Phase 1: Classification of land use by remote sensing imagery (NRI Bulletin 66)

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Bulletin 66

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Phase 1: Classification of land use by remote sensing imagery

Overseas Development Administration

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Summaries

SUMMARY

In areas of Africa affected by trypanosomiasis, tsetse control is a major component of rural development activities. It is undertaken to facilitate human settlement and agricultural change through the expansion of livestock-based production systems in areas cleared of tsetse. Its impacts need to be assessed within the context of sustainable land-use planning. As part of an international programme of work to evaluate the environmental and socio-economic impacts of tsetse control in southern Africa, its effects on land use and vegetation change over a 20-year period are being assessed using satellite imagery. The study area covers approximately 8500 km^2 south of Lake Kariba in Zimbabwe, and Phase 1 of the research programme used Landsat TM imagery and aerial photography to define baseline vegetation and land-use classes.

Black and white aerial photography for 1990 and a Landsat TM image for 19 February 1992 were used for the analysis. Bands 2, 3 and 4 were contrast-stretched to achieve maximum variation between spectral signatures and photographs prepared for ground truthing. Fieldwork was carried out in both the wet (February 1993) and dry (June 1993) seasons. More than 300 field sites were fixed using a global positioning system, and data were collected on geology, soil type, drainage and topography. All data coverages were incorporated in an ARC/INFO geographical information system (GIS).

As with previous work, the study showed that in regions of sparse vegetation, such as semi-arid and arid zones, vegetation classification from satellite imagery is strongly influenced by the soil background and the time of year the imagery was taken. Geological and topographic factors are also influential and, hence, manual classification of the satellite image was necessary with considerable reliance on ground survey data.

Fifteen land-use/vegetation classes were derived, four of which relate to human land use, bare soil and the effects of fire (16% of the land cover). *Colophospermum mopane* and a mosaic of *Colophospermum mopane* and *Julbernardia globiflora* woodlands were the predominant natural vegetation (54%) in the study area. Landsat TM and MSS imagery for seven years between 1972 and 1993 have been selected for Phase 2 of the study, which will quantify land use and vegetation changes in relation to the history of tsetse-control operations in the area.

RÉSUMÉ

Dans les régions d'Afrique affectées par la trypanosomiase, la lutte contre la mouche tsé-tsé est une composante majeure des activités de développement rural. Elle est menée à bien pour faciliter l'établissement des Hommes et les changements au niveau de l'agriculture, par le biais de l'expansion des systèmes de production basés sur l'élevage, dans les régions où la mouche tsé-tsé a été éliminée. Son impact doit être évalué dans le contexte de la planification d'une utilisation des terres durable. En tant que partie d'un programme international de travaux visant à évaluer les impacts environnementaux et socio-économiques de la lutte contre la mouch tsé-tsé en Afrique australe, ses effets sur les changements se produisant au niveau de l'utilisation des terres et de la végétation, au cours d'une période de 20 ans, sont en train d'être évalués en utilisant les images obtenues par satellite. La zone d'étude couvre 8500 km^2 environ, au sud du Lac Kariba au Zimbabwe et lors de la Phase 1 du programme de recherche, des images obtenues par Landsat TM et des photographies aériennes ont été utilisées pour définir la végétation d'origine et les catégories d'utilisation des terres.

Des photographies aériennes en noir et blanc pour 1990 et une image obtenue par Landsat TM le 19 février 1992 ont été utilisées aux fins de l'analyse. Le contraste a été augmenté dans les bandes 2, 3 et 4 pour obtenir une variation maximum entre les signaux spectraux et les photographies préparées pour la vérification au sol. Des travaux de terrain ont été effectués pendant la saison des pluies (février 1993) et la saison sèche (juin 1993). Plus de 300 sites ont été établis en utilisant un système de positionnement global et des données ont été recueillies sur la géologie, le type pédologique, le drainage et la topographie. Toutes les données ont été incorporées dans un système d'information géographique (SIG) ARC/INFO.

Comme pour les travaux précédents, l'étude a montré que dans les régions à végétation clairsemée, telles que les zones semi-arides et arides, la classification de la végétation à partir des images obtenues par satellite est fortement influencée par la réflexion du sol et l'époque de l'année

à laquelle les images étaient obtenues. Les facteurs géologiques et topographiques ont également une influence; par conséquent, une classification manuelle de l'image obtenue par satellite était nécessaire en se reposant considérablement sur les données de l'étude au sol.

Quinze catégories d'utilisation des terres/végétation en étaient tirées, dont quatre ont trait à l'utilisation des terres par l'Homme, au sol dénudé et aux effets du feu (16% du couvert). La végétation naturelle prédominante dans la zone d'étude (54%) consistait en *Colophospermum mopane* et en une mosaique de terres boisés avec *Colophospermum mopane* et *Julbernardia globiflora*. Les images obtenues par Landsat TM et MSS pendant sept années, entre 1972 et 1993, ont été sélectionnées pour la Phase 2 de l'étude qui quantifiera les changements qui se sont produits au niveau de l'utilisation des terres et de la végétation, par rapport à l'historique des opérations de lutte contre la mouche tsé-tsé dans la région.

Introduction

Bovine trypanosomiasis transmitted by tsetse flies has long been recognized as a major constraint to rural development and livestock production in Zimbabwe. Approximately half the country is climatically suitable for tsetse and only the central plateau above about 1100 m has no history of infestation (Lovemore, 1994). Successive Zimbabwean governments have attempted to alleviate the constraints imposed by trypanosomiasis by controlling the tsetse vectors through a variety of methods. In the early part of this century, bush clearance and the elimination of game animals were tried (Lovemore, 1994). Later insecticide spraying operations pushed tsetse back to and beyond Zimbabwe's international borders, until control operations were curtailed by the Independence War in 1970s. By the time Independence was declared in 1980, substantial reinfestation had occurred. Large-scale control efforts were resumed in 1982, with campaigns involving ground and aerial spraying (Hursey and Allsopp, 1983) and, more recently, odour-baited targets (Vale *et al.*, 1988) (Figure 1), so that tsetse are now largely confined to the Zambezi Valley and the northern border with Mozambique (Figure 1). An estimated US$ 6 million have been spent each year containing tsetse at its current limits, and clearing the western part of the tsetse belt in the region of Lake Kariba is considered a cost-effective control option since it reduces the length of the tsetse 'front' in the Zambezi Valley (Barrett, 1989).

Human population pressure in Zimbabwe, as in many other African countries, has led to large-scale migrations of people from heavily populated areas to regions cleared of tsetse, particularly in peasant farming areas (Communal Lands), leading to the conversion of natural habitats into human-dominated landscapes. Communal farmland covers an area of approximately 163 000 km^2 in Zimbabwe and comprises nearly 50% of the land use in agro-ecological regions characterized by erratic rainfall of less than 650 mm a year. They are designated as suitable for livestock production and game ranching (Murphree and Cumming, 1993). Human population growth in these areas is the highest in the country (3% per year; Zinyama and Whitlow, 1986). Although the Communal Lands are diverse in character throughout the country, mixed farming predominates, involving individually farmed arable plots, approximately 3 ha in area, and communal grazing of livestock (Barrett, 1989). About 80% of the households in the Communal Lands keep grazing animals principally for draught purposes. This enables farmers to cultivate larger areas and achieve better crop yields because of more efficient and timely land cultivation (Barrett, 1989).

The introduction or development of livestock production in an area is not dependent on tsetse control. However, removal of tsetse tends to accelerate livestock productivity and leads to increases in cattle numbers and the availability of draught animals, and changes in the composition and structure of livestock herds (Reid, 1994). High populations of livestock have been a feature of the Communal Lands for several years (Scoones, 1992a), and have resulted in large returns both per animal and per hectare (Scoones, 1992b), but the trade-offs between high stocking rates, outputs and potential environmental costs have not been fully evaluated (Scoones, 1992b). The possibility of environmental degradation in tsetse-cleared areas that have been opened up to livestock and settlement has meant that tsetse control has remained a contentious issue (Barrett *et al.*, 1991; Jordan, 1992). There is a growing awareness of the importance of supporting the implementation of control programmes with resource and economic data on potential land use (Prankherd, 1991), and a recognition that tsetse control is simply one component of rural development and that its effects should be evaluated within a land-use planning framework. There is, however, little factual evidence on agricultural development in tsetse-cleared areas.

In this study, satellite imagery was used to assess the effects of tsetse-control measures on land-use practices and vegetation over a 20-year period in a semi-arid area south of Lake Kariba (Figure 1). This work (funded by the Overseas Development Administration of the British Government) forms part of an internationally co-ordinated research programme aimed at assessing the environmental and socio-economic impacts of tsetse control in southern Africa. It was carried out in collaboration with the TTCB (Tsetse and Trypanosomiasis Control Branch of the Department of Veterinary Services, Zimbabwe) and ILRI (International Livestock Research Institute), with additional support being provided by the RTTCP (Regional Tsetse and Trypanosomiasis Control Programme), WWF (World Wide Fund for Nature) and Agritex (Department of Agricultural Technical and Extension Services, Zimbabwe).

The study area, which covers approximately 8500 km^2, includes the Manjolo and Siabuwa Communal Lands, where settlement and agricultural development (including cattle rearing) has accelerated since the Independence War; the Omay Communal Land, which is settled but where cattle are excluded; and the Cheti Safari Area, Chizarira National Park and Sijarira Forest Area, which are cleared of tsetse but have no human-settlement development (Figure 2). Tsetse distribution and density increases from south to north in the study area. In the south, tsetse has not been a problem since the beginning of the century, when the rinderpest outbreak caused a fall in numbers of the wild hosts of the fly. In the Binga area (Figure 2), tsetse was successfully elimated by 1983, while further north, the insect still occurs (Lovemore, 1994).

Population density in the Communal Lands in the study area remains amongst the lowest in the country at <10 persons/km^2 in 1982, compared to an average of 25.5 persons/km^2 for the Communal Lands as a whole (Zinyama and Whitlow, 1986). This is partly due to the remoteness of the region and the marginal nature of the land. The traditional agriculture of the Batonga inhabitants of the region was based on hunting, gathering and opportunist rainfed/floodwater cultivation, with little or no dependence on livestock, reflecting both the historical threat from tsetse and the need to evolve a system of agriculture adaptable to sudden changes in water availability before the creation of Lake Kariba (Scudder, 1982; Murphree and Cumming, 1993). Since the filling of Lake Kariba in 1960 and the implementation of tsetse control, parts of the study area (in particular, the Manjolo Communal Land) have experienced influxes of people and the expansion of subsistence agriculture, including livestock production. The land is being settled at the rate of about 4% a year (Cumming, 1994; Murphree and Cumming, 1993).

In order to examine the trends in land-use practices in the study area, the first phase of the work used remotely sensed imagery to define and quantify current vegetation and land-use patterns, and establish the baseline vegetation/land-use classification against which the analysis of historical changes will be carried out.

Previous work using remote sensing to classify land use and vegetation

Aerial photography and Landsat satellite imagery have been used in a number of studies to assess land use and vegetation cover in semi-arid and arid regions of southern Africa. Changes in the volume of woody cover have been described, and the risk of soil erosion assessed in Zimbabwe, using conventional visual analysis of aerial photographs (Whitlow, 1980; 1987). Other workers have used aerial photographs to assess percentage change in tree canopy as a measure of overgrazing in Zululand, Republic of South Africa (RSA) (Watson and MacDonald, 1983); changes between arable land use, natural vegetation and soil erosion in the Yellowwoods catchment area, RSA (Weaver, 1988); and changes in vegetation patterns and land use in Transkei (MacKenzie, 1989), along the Natal coast (Weisser and Marques, 1979), and near Gaberone, Botswana (Ringrose, 1987).

In Botswana, Ringrose *et al.* (1990) used Landsat images, covering five wet seasons between 1972 and 1987, to evaluate land-use change in relation to climate, population and cattle data. Fifteen vegetation classes were separated with an accuracy of 84% to 93% and validated for 1984, using detailed ground data and colour aerial photographs. The most accurate results from the satellite classification were obtained for the wet season in which the validation was carried out and classification accuracy decreased with time (Ringrose *et al.*, 1990). Previous attempts to map land use and vegetation in Zimbabwe have found it necessary to include topography and hydrology to delimit vegetation and land-use classes (Andersen, 1988; Kappeyne, 1984; 1985; Whitlow, 1987). Pilot-study, land-use maps at 1:250 000 have been produced for Matabeleland with 12 classes, identifying forests with different species composition, grasslands and cultivated land (Kappeyne, 1984; Kappeyne *et al.*, 1983). This study indicated that detailed classifications with more than 12 vegetation groups were difficult to relate to ground surveys, and that fewer groups gave an unsatisfactory, coarse classification (Kappeyne *et al.*, 1983). Later work pointed to the need to increase the number of classes to 20 due to the effect of topography on the vegetation (Kappeyne, 1985).

A survey of the Communal Lands in the Zambezi valley, based on aerial photographs and Landsat MSS (Multi-Spectral Scanner) satellite imagery (Timberlake *et al.*, 1991; Timberlake *et al.*, 1993), identified eight main physiognomic-floristic groups, further divided into 37 subclasses, according to vegetation structure and characteristic species. Landsat MSS data are also being used by the Zimbabwe Forestry Commission to survey forest cover (Bird, 1992) and produce maps at scales of 1:250 000 and 1:1 million, although this work does not differentiate woodland by species composition (Gondo and Traub, 1993).

The validity of land-use interpretation in semi-arid and arid areas from remotely sensed data is partly dependent on the time of year the imagery was taken. Dry-season imagery is of limited use for defining agricultural land or rangeland (e.g. Ringrose, 1987), while assessments of woody biomass usually require dry-season images without the reflectance due to underlying grasses (Vujakovic, 1987). For example, several tree species, including the indigenous southern African *Colophospermum mopane*, retain their leaves during part of the dry season and are, therefore, spectrally distinctive from all other vegetation at the beginning and end of the growing season (Prince and Astle, 1986).

Classification techniques for satellite images that have been used to provide indicators of vegetation condition and vigour in wetter regions are not so effective in semi-arid and arid areas, where a major constraint to their use is the 'darkening effect' in areas of relatively sparse vegetation that distorts the expected spectral response (Ringrose and Matheson, 1987; 1991). This darkening effect has been shown to be intimately correlated with soil type and condition, as well as plant shadow factors, which can be especially important when the image is taken at a low solar angle (Cherlet and Di Gregorio, 1991; Ringrose and Matheson, 1991). Soils that are dark in colour or wet may lead to an over-estimation of vegetation cover, while highly reflective, light-coloured, dry soils can mask the vegetation and result in under-estimation (Cherlet and Di Gregorio, 1991). In the wet season, the darkening effect can be lessened by grass cover.

The accuracy of classifications is improved by considering the red band (MSS band 5, TM (Thematic Mapper) band 3) rather than the commonly used vegetation indices (e.g. Normalized Difference Vegetation Index (NDVI), Vegetation Index (VI)) (Kappeyne *et al.*, 1983; Kappeyne, 1984; Ringrose and Matheson, 1987; 1991). For example, in Botswana, Vujakovic (1987) achieved a 79% accuracy in savanna woodland classification with MSS band 5. Other work, on sparsely vegetated areas of the Sahel, obtained good classifications when TM band 3 was included in the analysis, although the best classification accuracy was achieved using the Perpendicular Vegetation Index (PVI), which measures the reflectance value of the red and infra-red bands as the perpendicular distance to reflectance values of the soil, represented as a sloping line on a red/infra-red reflectances plot (Cherlet and Di Gregorio, 1991). This technique, however, takes a lot of computing effort and is not as effective in areas of multilayered vegetation, such as savanna woodland in the wet season (Ringrose and Matheson, 1991).

Background to the study area

GEOLOGY

The study area covers 8478 km^2 and extends from 16° 50′ S at the Bumi Hills in the north, to 18° 10′ S south of Mlibizi (Figure 2). It is characterized by rocks ranging in age from Precambrian gneisses and late Precambrian deposits of the Sijarira group, through formations of the Karoo succession of Permian, Triassic and Jurassic times, to aeolian and alluvial deposits of Pleistocene and recent origin (Figure 3) (Stagman, 1978). The late Precambrian Sijarira deposits are grits, sandstones and conglomerates, which form most of the Chizarira National Park as a block faulted horst of gently dipping beds, with the highest point in the northeast at Tundazi. These beds overlie a gneissic basement composed of feldspar, quartz and mica, which is exposed to the southwest of the Chizarira Plateau, north of Cockcroft Bridge (Figure 3).

The Karoo succession covers most of the remaining study area. The earliest rocks in this succession are glacial deposits lying discontinuously on the Sijarira beds and composed of tillites overlain in some places by coal. These are found exposed north of the Chizarira Plateau in the Siabuwa area and, more extensively, south of the Plateau. Elsewhere, later Karoo deposits are represented by a succession of sandstones, mudstones, conglomerates and grits. The Karoo period ended with outpourings of basaltic lavas, which are found in parts of the Omay Communal Land (Figure 3).

Pleistocene deposits occur in the Manjolo Communal Land with the windborne deposits of the Kalahari sands. There are also deposits of more recent alluvium along the foot of the escarpments and in the river valleys throughout the area (Figure 3).

DRAINAGE AND LANDFORMS

The study area lies within the drainage system of the Zambezi, with all rivers draining into Lake Kariba. Elevation varies from 480 m at Lake Kariba to 1439 m at Tundazi, the highest point of the Chizarira Escarpment (Figures 2 and 3).

In the Omay Communal Land in the north of the study area, the land is rugged with northeast-southwest aligned hills, and the area is drained by structurally controlled seasonal streams and rivers. Longer rivers, such as the Sengwa, which originate in wetter regions outside the study area, have some waterflow during most of the dry season. In the extreme north near the Bumi Hills, there are some rolling, flatter areas around Mola and in the lower Sengwa valley.

In the northern Siabuwa Communal Land, a landscape of rolling hills decreases in height southwards to the Lwzilukula and Mucheni valleys (Figure 2). The streams are again ephemeral and drainage is governed by the permeability of the grits and sandstones of the Karoo beds. South of the Siabuwa Communal Land, the Chizarira Escarpment is punctuated by a series of steep gorges that drain the lower interior of the plateau. Drainage on the plateau is in shallow valleys with broad, flat interfluves that have a dendritic drainage pattern in the southwest and a rectilinear drainage pattern in the northeast (Figure 2). Perennial springs in the shallow valleys give rise to *vleis* of permanent grassland.

Near Lake Kariba in the Binga area, there is a series of northeast-southwest aligned escarpments with rolling hills that govern drainage patterns. Further inland, there is an area of negligible surface drainage, coinciding with highly permeable deposits of Kalahari sands, which is bordered on the south by a narrow area of alluvium (Figures 2 and 3).

SOILS

The soils throughout the study area are closely associated with the geology. On the slopes of the escarpments and in the hilly areas, the soils are generally shallow and undeveloped, with frequent rock outcrops and a high pebble content. For example, north of Cockcroft Bridge, quartz and mica pebbles up to 5 cm in diameter are frequently found on the surface of gneiss. Similar pebble areas occur on the gritstones of the Karoo beds, which have shallow soils with many exposed pebbles and poorly developed vegetation (Figure 4).

On finer-grained sandstones, sandy soils of varying depths develop. The quality of these soils varies according to slope, derived sodic content and the water-holding capacity of the soil. The Kalahari sand deposits give rise to extremely permeable soils with little clay content (Nyamapfene, 1986).

At the base of escarpments, there are often alluvium deposits, as in the Manjolo Communal Land (Figure 3), and limited alluvial soils occur along the main river valleys. In the Omay Communal Land, dark clay soils are derived as alluvial deposits from the basalt forming the Ruokuvo Hills. These soils, although deep, have a high sodic content which prevents their use for cultivation (Brinn and Moyo, 1987; Bromley and Jones, 1966).

CLIMATE

The study area has a semi-arid climate with an average yearly rainfall of less than 1100 mm. Rainfall decreases in a southwesterly direction, with average rainfall of 1030 mm at Bumi Hills (Brinn and Moyo, 1987), 655 mm at Siabuwa and 620 mm at Binga (Anderson *et al.*, 1993). Most rain falls between October and April (Figure 5), although there are considerable variations within and between years (Figure 6).

There is little variation in mean monthly temperatures throughout the year, with an average of 24 °C in the dry season and 27 °C in the wet season.

VEGETATION

In the Zambezi valley below 1300 m, areas not mantled by Kalahari sand are dominated by *Colophospermum mopane* woodlands that, with thicket vegetation along the Zambezi escarpment, account for 17.5% of the country's land cover (Cole, 1986). These woodlands vary between a continuous canopy of *Colophospermum mopane* with underlying grass cover, to a more open woodland in drier areas, with variations in plant associations according to geomorphology and bed-rock geology. Similar savanna woodland of varying tree/grass density occurs in the Limpopo valley, Botswana and in the Transvaal lowveld areas of RSA, and is associated with a summer (December to March) rainfall regime (Cole, 1986).

Timberlake *et al.* (1993) found that miombo woodland, dominated by *Brachystegia* species and *Julbernardia globiflora* is the most extensive vegetation class within the Communal Lands of Zimbabwe (38.9%), and occurs in the study area above 1200 m. They failed to identify any vegetation belonging to riparian forest and alluvial woodland class in the study area, but six of the main vegetation groups were found, and apart from mopane and miombo woodlands, the other vegetation types are associated with grasslands and thickets dominated by shrubs of *Combretum* species (Table 1).

Table 1 Lake Kariba study area vegetation complexes as classified by Timberlake *et al.* (1993)

Vegetation complex	Characteristics	Shrub-layer species	Tree-layer species	Location
C. Dry forests and thickets				
C3. *Combretum* woodland thicket on colluvium and sandstone	Dense shrubs 20–90% cover	*Combretum celastroides* *Combretum elaeagnoides* *Meiostemon tetrandus* *Dalbergia martinii*	*Xeroderris stuhlmannii* *Pteleopsis myrtifolia* *Lannea schweinfurthii* *Colophospermum mopane*	North Siabuwa, Chizarira escarpment, Kariangwe
C4. *Guibourtia conjugata* woodland thicket	Dominated by slender trees or shrubs	*Combretum celastroides* *Combretum elaeagnoides* *Baphia massaiensis* *Meiostemon tetrandus*	*Guibourtia conjugata* *Combretum collinum* *Strychnos madagascariensis* *Pteleopsis myrtifolia* *Diospyros quiloensis* *Commiphora karibiensis* *Pterocarpus lucens* *Xeroderris stuhlmannii* *Lannea schweinfurthii*	North Binga
D. Miombo woodlands				
D3. Open woodland on sandstone plateaux	Varied vegetation with *Brachystegia boehmii* and *Julbernardia globiflora*	regenerating trees *Baphia massaiensis* *Bauhinia petersiana* *Flacourtia indica* *Catunaregnum spinosa* *Pavetta schumanniana* *Strychnos spinosa* *Bridelia cathartica* *Grewia monticola*	*Brachystegia boehmii* *Julbernardia globiflora* *Burkea africana* *Combretum zeyheri* *Diplorhynchus condylocarpon* *Pseudolachnostylis maprouneifolia*	Chizarira, Omay, South Siabuwa
D4. Woodland on shallow soils	Low, open woodland with tall, poorly developed grass		*Julbernardia globiflora* dominant *Combretum appiculatum* *Diplorhynchus condylocarpon* *Colophosphermum mopane* *Pseudolachnostylis maprouneifolia* *Xeroderris stuhlmannii* *Combretum zeyheri*	North Manjolo

Table 1 Lake Kariba study area vegetation complexes as classified by Timberlake *et al.* (1993)—*continued*

Vegetation complex	Characteristics	Shrub-layer species	Tree-layer species	Location
D6. *Brachystegia glaucescens* woodland on hills	Open woodland with poor shrub and grass layers		*Brachystegia glaucescens* *Brachystegia boehmii* *Julbernardia globiflora*	Chizarira
E. Miombo-mopane woodlands				
E2. *Julbernardia-Colophospermum* woodland catena	Varied on shallow soils derived from Karoo sandstone, *Julbernardia globiflora* on higher points, poor shrub layer with *Colophospermum mopane*	*Baphia massaiensis* *Combretum appiculatum* *Acacia nilotica* *Mundulea sericea* *Erythroxylum zambesiacum* *Boscia mossambicensis* *Ximenia americana* *Courbonia glauca*	*Julbernardia globiflora* + *Pteleopsis anisoptera* *Combretum zeyheri* *Diplorhynchus condylocarpon* *Burkea africana* *Crossopteryx februgia* *Monotes engleri* *Pteleopsis myrtifolia* *Pseudolachnostylis maprouneifolia* *Colophospermum mopane* + *Terminalia stuhlmannii* *Terminalia pruniodes* *Diospyros quiloensis*	Siabuwa, Manjolo, South Omay
F. Mopane woodlands				
F2. *Colophospermum-Terminalia stuhlmannii* woodland	Co-dominance woodland thin bush layer	*Acacia nilotica* *Grewia flavescens* *Ximenia americana* *Dalbergia melanoxylon* *Gardenia resiniflua* *Grewia bicolor*	*Colophospermum mopane* *Terminalia stuhlmannii* *Kirkia accuminata* *Erythroxylum zambesiacum* *Commiphora mollis* *Commiphora glandulosa* *Acacia nilotica* *Combretum appliculatum* *Commiphora mossambicensis*	Siabuwa, Omay

F3. *Colophospermum* woodland (single dominance)	Uniform woodland, low importance of other species, or relatively level terrain	*Burkea africana* *Grewia monticola* *Maerua prittwitzii* *Boscia mossambicensis* *Boscia matabelensis* *Grewia bicolor* *Courbonia glauca* *Combretum elaeagnoides*	*Colophospermum mopane* + *Acacia nilotica* *Diospyros quiloensis* *Dichostrachys cinerea* *Dalbergia melanoxylon* *Ximenia americana*	South Binga, Siabuwa, West Omay
G. Combretaceae open woodlands				
G1. *Combretum collinum* open woodland on sand	Open woodland to bushlands with well-developed shrub layer	*Grewia flavescens* *Grewia monticola* *Dichostrachys cinerea* *Bauhinia petersiana* *Rhus tenuinervis* *Acacia ataxacantha* *Vangueria infausta*	*Combretum collinum* *Combretum zeyheri* *Combretum appiculatum* *Terminalia sericea* *Burkea africana* *Ochna puchra* *Peltophorum africanum*	Mlibizi
J. Grasslands				
J2. *Cynodon-Eragrostis* grassland on sand	Open low grasslands on poorly drained soils			Water courses' drainage lines
J4. *Panicum repens* lakeshore grassland	Grassland with scattered trees and dead mopane stumps	*Phyllanthus reticulatus* *Sesbania* sp.	*Acacia tortilis* *Adansonia digitata*	Binga, Omay

Materials and methods

AERIAL PHOTOGRAPHY

The most recent aerial photographs available (black and white panchromatic coverage, dated July 1990) were used to delimit vegetation and landforms in part of the study area in order to assess the potential of aerial photography as an aid to interpreting land use and vegetation patterns from satellite imagery. Aerial photographic interpretation (API) was undertaken for two contrasting parts of the study area, Binga and the northern Manjolo Communal Land, and part of the Chizarira National Park (Figures 2 and 9).

Preliminary land unit interpretation of the photographs was transferred using a Grant's Projector to a 1:50 000 base map enlarged from the 1:100 000 Lake Kariba Chart 3 (published by Surveyor General, Harare, 1984). The interpretation was based on a standard vegetation structure key, identifying the percentage cover of trees and shrubs, and the major landform types.

THEMATIC MAPPER IMAGERY

Landsat scene 172/72 includes the whole study area (Figure 7) and cloud-free TM satellite imagery for bands 2, 3, 4 and 5 was obtained for 19 February 1992 (Figure 8). The image was extremely good, with sharp spectral contrast in each band. A combination of bands 2, 3 and 4 produced the clearest distinction between the vegetation types in the study area. These bands were contrast stretched to give maximum variation between the spectral signatures and the results were photographed from the screen using a 200 ASA colour print film at a fixed speed of 1/30 second. 10" × 12" photographic prints were prepared for fieldwork.

FIELDWORK

Fieldwork was undertaken in both the wet (February 1993) and dry season (June 1993) (Figure 9). The wet-season work concentrated on field checking the API of the Binga area and the northern Manjolo Communal Land. Survey sites during this period were chosen to be representative of as many of the API classes as possible (Figure 10, wet-season survey sites 1–101). The June fieldwork concentrated on field checking the TM imagery and API of part of the Chizarira National Park (Figure 11, dry-season survey sites 1–224). Point observations were made at locations fixed by a Global Positioning System (GPS) instrument and at each survey point observations were made of the vegetation species composition (Appendix 1), density of grass, shrub and tree layers, geology, soils, landforms and drainage.

Survey points were chosen to cover the unique spectral patterns discernible on the TM imagery. Several points with similar spectral responses were visited until the vegetation could be predicted from the imagery. Point-survey information, was supplemented by transect data, largely along roads and tracks, but including foot transects (Figures 9 to 11).

POST-FIELDWORK CLASSIFICATION OF THE AERIAL PHOTOGRAPHY

Terrain units were reclassified from the original interpretation, with nine classes defined for Binga and the northern Manjolo Communal Land, and six for the Chizarira National Park (Table 2). Individual tree and bush species could not be identified from the aerial photographs, but fields and grazed areas could be mapped from the Binga and northern Manjolo Communal Land API. There is no human settlement in the Chizarira National Park.

Table 2 Terrain units identified from aerial photographs of (a) Binga area and northern Majolo Communal Land and (b) Chizarira National Park

(a)	(b)
1. Mountain greater than 700 m	1. Scarp slope
2. Hill 500–700 m	2. Footslope
3. Undulating to rolling land with frequent changes of slope	3. Valley
4. Valley	4. Plateau, deep dendritic drainage
5. Gently undulating plain	5. Plateau, shallow dendritic drainage
6. Footslope	6. Plateau, rectilinear drainage
7. Scarp slope or cliff face	
8. Footslope overlain with colluvium or alluvium	
9. Lakeshore	

POST-FIELDWORK CLASSIFICATION OF THE SATELLITE IMAGERY

The wet-season image for February 1992 covered a period of severe drought throughout southern Africa, with Binga receiving less than 50% of its average rainfall, and the maximum occurring in March when the growing season had ended (Figure 6). This resulted in an almost complete failure of crops in the study area, with bare land reflectances similar to that of a typical early dry-season image after harvest in cultivated areas. Natural grasslands also frequently appeared as bare soil on the image, as did areas near the lakeshore where the water level had fallen. There were very few places with a vegetation canopy cover greater than 50%, and hence, the effects of soil types and surface geology strongly influenced the vegetation classification on the imagery.

Attempts at supervised and unsupervised classification of the image, based on the June field data, were not successful, since the spectral signatures of each vegetation type varied due to variations in surface geology. For example, the gneisses to the north of Cockcroft Bridge imposed a grey tinge on the stretched image, while gritstones of the Karoo beds had the effect of adding blue (Figure 12), which resulted in two different spectral responses for mopane woodland.

Conversely, some land-use classes had the same spectral signatures, although field observations showed they were the result of different factors. For example, bare soil could be due to cultivation, changing lake levels or fire, but these cannot be distinguished in an automatic classification of the image. Manual classification of the image was therefore undertaken, with reference to the geological map (Figure 3) and the field notes.

DATA INTEGRATION

In order to produce a 1:250 000 map of vegetation and land use for 1992 and provide baseline data for the historical analysis of land use and vegetation change in Phase 2 of the study, additional geographical data have been integrated in a geographical information system (GIS) (ARC/INFO). These data, which were derived from a variety of sources, were geo-referenced and converted to a Universal Transverse Mercator (UTM) projection and grid system, which is widely used in Zimbabwe. A list of coverages and their sources is given in Table 3.

Table 3 Geographical information system (GIS) coverages

Coverage	Source of information
(a) Lake Kariba study area	
Vegetation and land use during February 1992	Thematic Mapper imagery
Drainage	1:250 000 1982 ed. (ZSG)*
Roads	ILRI† dataset
Administrative boundaries	1:500 000 1974 ed. (ZSG)
Settlement	1:250 000 1982 ed. (ZSG)
Geology	1:1 000 000 1991 ed. (ZSG)
Field study survey sites and routes	Sites fixed by GPS‡, routes based on roads and GPS
Areas covered by ground-spray tsetse control operations	Tsetse Control Branch, Harare
Areas covered by aerial-spray tsetse control operations	Tsetse Control Branch, Harare
Area covered by Thematic Mapper Image 172/73	Thematic Mapper imagery
1993 distribution of tsetse flies	Tsetse Control Branch, Harare
(b) Manjolo Communal Land	
Terrain units	1990 aerial photography
Human land use	1990 aerial photography
50-m contours	1:100 000 (chart) 1977
(c) Chizarira National Park	
Landforms	1990 aerial photography

Notes: * ZSG Zimbabwe, Surveyor General
† ILRI International Livestock Research Institute
‡ GPS Global Positioning System

Results

TERRAIN UNIT CLASSIFICATION

The Binga area and northern Manjolo Communal Land are dominated (36%) by an undulating or rolling landscape with a series of northeast-southwest aligned escarpments on deposits of Karoo sandstones or Kalahari sands. The land slopes towards Lake Kariba from mountains in the southeast, over 700 m high, bounded by a line of hills between 500 and 700 m high that comprise 23% of the terrain classification. A broken line of similar hills borders Lake Kariba (Figure 13). Human-dominated land use, as exemplified by settlements, fields and over-grazed land, is confined to the undulating land on the Kalahari sands and a broad belt of alluvium that comprises 14% of the landscape (Figure 13).

A broad plateau with a shallow dendritic drainage pattern is the dominant (47%) terrain unit derived from the API of part of the Chizarira National Park (Figure 14). The plateau drainage becomes rectilinear to the east (9%) and deeply dendritic elsewhere (7%), and the plateau is bordered by steep scarp slopes that cover 12% of the landscape in the area (Figure 14).

VEGETATION CLASSES

Survey work in the study area showed that the natural vegetation classes identified by Timberlake *et al.* (1993) could be used as a basis for classifying the TM imagery into 15 vegetation classes (Table 4). The relationship of these classes to those of Timberlake *et al.* (1993) are given in Table 5.

Table 4 Lake Kariba study area vegetation classes

1. Human land use dominant over natural vegetation

Grassland
2. Grasses in well-watered areas
3. Grasses around lakes and dams
4. Grasses regrowing after burning

Woodland
5. *Colophospermum mopane* woodland
6. Woodland with *Julbernardia globiflora*
7. Woodland with dense *Combretum* spp. shrubs
8. Mosaic of *Colophospermum mopane* and *Julbernardia globiflora* woodland
9. Complex of *Guibourtia conjugata* and *Combretum* spp.
10. Mixed woodland on lower hills
11. Mixed woodland on escarpments
12. Miombo woodland with *Brachystegia boehmii* and *Julbernardia globiflora*
13. Riverine woodland

Bare soil
14. Fire-affected area
15. Bare soil area of unidentified origin

Table 5 Relationship between vegetation classes defined in the present study and those of Timberlake *et al.* (1993)

Class	Equivalent class in Timberlake *et al.* (1993)
1. Human land use dominant over natural vegetation	No equivalent class
2. Grasses in well-watered areas	J2. *Cynodon-Eragrostis* grasslands on sands
3. Grasses around lakes and dams	J4. *Panicum repens* lakeshore grassland
4. Grasses regrowing after burning	No equivalent class
5. *Colophospermum mopane* woodland	F. Mopane woodlands
6. Woodland with *Julbernardia globiflora*	D4. Miombo woodlands on shallow soils
7. Woodland with dense *Combretum* spp. shrubs	C3. *Combretum* woodland thicket on colluvium and sandstone
8. Mosaic of *Colophospermum mopane* and *Julbernardia globiflora* woodland	E2. *Julbernardia*/mopane woodland catena
9. Complex of *Guibourtia conjugata* and *Combretum* spp.	C4. *Guibourtia conjugata* woodland thicket
10. Mixed woodland on lower hills	C4. *Guibourtia conjugata* woodland thicket
11. Mixed woodland on escarpments	C4. *Guibourtia conjugata* woodland thicket and D6. *Brachystegia glaucescens* woodland on hills
12. Miombo woodland with *Brachystegia boehmii* and *Julbernardia globiflora*	D3. Miombo woodlands
13. Riverine woodlands	B. Riparian forests and alluvial woodlands
14. Fire-affected area	No equivalent class
15. Bare soil area of unidentified origin	No equivalent class

Timberlake *et al.* (1993) considered only natural vegetation and the four classes relating to human land use, bare soil and the effects of burning in the present study, have no equivalent in the Timberlake *et al.* (1993) classification. The subdivision of *Guibourtia conjugata* woodland thicket (Table 1, Class C4) into two separate classes, for the complex in the northern Manjolo Communal Land and for the mixed woodland on the lower hills of the Binga area, can be justified by the more varied tree layer and less dense thicket layer in the latter (Table 5, Classes 9 and 10). The two classes are also texturally distinct on the TM image. Timberlake *et al.* (1993) subdivided mopane woodland into two classes in the study area, according to the presence or absence of a bush layer and other tree species (Table 1, Classes F2 and F3). In this study, all woodland containing *Colophospermum mopane* is in a single class (Table 5, Class 5). Forests and woodlands, which fringe rivers or large watercourses were not found in the study area by Timberlake *et al.* (1993), but have been identified from the satellite image in this study and included as Class 13 (Table 5).

Appendix 1 lists the species found at the survey sites and Appendix 2 gives a complete list of species found in each vegetation class. The 15 vegetation classes have been manually classified on the image and digitized into the GIS to produce a 1:250 000 map of the land use and vegetation in the study area in 1992 (Map 1).

The total area of each land use and vegetation class is given in Table 6. *Colophospermum mopane* woodlands and a mosaic of *Colophospermum mopane* and *Julbernardia globiflora* woodlands together, cover 54% of the area, which agrees with the classifications in previous surveys of the vegetation in semi-arid and arid areas in Zimbabwe (Boughey, 1961; Cole, 1986; Henkel, 1931). Human-dominated land use is the next most extensive class (12.6%), followed by miombo woodland (7.5%).

Table 6 Area assigned to each vegetation/land-use class

Class	Area (km²)	% of total area
1. Human land use dominant over natural vegetation	1071.4	12.64
2. Grasses in well-watered areas	63.3	0.75
3. Grasses around lakes and dams	62.38	0.74
4. Grasses regrowing after burning	8.66	0.10
5. *Colophospermum mopane* woodland	1499.18	17.68
6. Woodland with *Julbernardia globiflora*	365.12	4.31
7. Woodland with dense *Combretum* species shrubs	390.36	4.60
8. Mosaic of *Colophospermum mopane* and *Julbernardia globiflora* woodland	3046.91	35.94
9. Complex of *Guibourtia conjugata* and *Combretum* species	206.07	2.43
10. Mixed woodland on lower hills	220.44	2.60
11. Mixed woodland on escarpments	420.10	4.95
12. Miombo woodland with *Brachystegia boehmii* and *Julbernardia globiflora*	637.49	7.52
13. Riverine woodland	225.17	2.66
14. Fire-affected area	225.17	2.66
15. Bare soil area of unidentified origin	62.54	0.74
	8477.93	100

CLASS 1. HUMAN LAND USE DOMINANT OVER NATURAL VEGETATION

This class could be identified on both the TM imagery and aerial photographs, and includes built-up areas such as the town of Binga, and airstrips, rural settlement and cultivated areas. In rural areas, settlement cannot be separated from the surrounding cultivated land as most settlement units consist of individual extended families living close to their fields (Figure 15). Crops grown include sorghum, maize, millet and vegetables. Few commercial crops are cultivated, apart from a small area of cotton around Mola. Throughout the study area, goats were seen grazing and cattle are kept in the Siabuwa, Manjolo, Kariangwe and Mlibizi areas. Five main settlement zones could be identified, three distinct areas in the Manjolo Communal Land (west of Binga, between Mlibizi and Cockcroft Bridge, and the Sebungwe valley near Kariangwe), and the Siabuwa and Omay Communal Lands.

It was not possible to subdivide this class using satellite imagery, although divisions into settlement, cultivated areas and grazing lands could be made using aerial photographs. In addition to the settlement and agricultural development identified by the API of the Binga area and northern Manjolo Communal Land (Figure 13), this land-use class was found on the footslopes bordering the northern edge of the Chizarira National Park.

CLASS 2. GRASSES IN WELL-WATERED AREAS

The larger river valleys, such as the Sengwa, have water for most of the year and contain extensive grassed areas. Other sources of perennial water are permanent springs, such as those on the Chizarira Plateau, which give rise to raised bog and grasslands (Figure 16).

CLASS 3. GRASSES AROUND LAKES AND DAMS

Perennial grasslands have been created by the formation of Lake Kariba and around smaller dams elsewhere (Figure 17). On the shores of Lake Kariba, many of these areas were originally *Colophospermum mopane* woodland, and stumps of dead trees are visible in the grassland. A sudden change to woodland occurs as the land rises away from the water body and the water table is no longer close to the surface.

CLASS 4. GRASSES REGROWING AFTER BURNING

Natural fire occurs throughout the woodlands of the study area, after which grass regrowth often occurs, becoming the dominant spectral signature in the dry season (Figure 18).

CLASS 5. *COLOPHOSPERMUM MOPANE* WOODLAND

Open woodlands where *Colophospermum mopane* is present as a single dominant species are at altitudes below 1100 m and are characterized by a poorly developed grass layer and few shrubs (Figure 19). The height of the *Colophospermum mopane* varies according to soil depth, from 4 m to tall, cathedral mopane, reaching 18 m.

Although much of the mopane woodland has a dominance of *Colophospermum mopane,* variations occur with the occasional presence of other species, such as *Combretum* spp., *Diospyros* spp. and *Acacia* spp., and less frequently, *Adansonia digitata, Kigelia africana* and *Kirkia acuminata* (Appendix 2). In the Binga area, greater species variety occurs as *Colophospermum mopane* woodland grades into a thicket of *Guibourtia conjugata* and *Combretum* spp. (Table 4, Class 9).

CLASS 6. WOODLAND WITH *JULBERNARDIA GLOBIFLORA*

In areas below 1100 m, an open mixed woodland occurs in which *Julbernardia globiflora* is the most common species, together with *Burkea africana, Diplorhyncus condylocarpon, Crossopteryx febrifuga* and *Pseudolachnostylis maprouneifolia* (Figure 20) (Appendix 2). There is also a shrub layer, with *Baphia massiensis* subsp. *obovata* and *Combretum* species. At higher levels and on better-drained soils, this class graduates into miombo woodlands of *Brachystegia boehmii* and *Julbernardia globiflora* (Table 4, Class 12), while at lower levels it is replaced by woodlands of *Colophospermum mopane* (Table 4, Class 5). Woodland with *Julbernardia globiflora* is negligible in the Chizarira National Park, but dominates the footslopes and low-lying hills in the Binga area and northern Manjolo Communal Land (Figure 13).

CLASS 7. WOODLAND WITH DENSE *COMBRETUM* SPP. SHRUBS

This woodland has a dense shrub layer up to 4 m high, usually including *Combretum elaeagnoides,* as well as other species of *Combretum* (Figure 21). It is found on soils derived from Karoo sandstone or Kalahari sands. This vegetation appears on low plateaux to the east of Mlibizi, where much of the area is now settled and cultivated. *Combretum* shrubs remain on the rim of escarpments at the edges of the plateaux and extend for about 100 m before the mixed woodlands of the escarpment begin (Table 4, Class 11). There are also patches of this type of vegetation north of the Siabuwa settled area and on the hills west of Mola, and larger areas along the lake shore in the Chete Safari Area.

CLASS 8. MOSAIC OF *COLOPHOSPHERMUM MOPANE* AND *JULBERNARDIA GLOBIFLORA* WOODLAND

A dissected landscape underlain by Karoo sandstones occurs between the cultivated areas of the Siabuwa Communal Land and those of the lower Sengwa valley to the north, including the eastern parts of the Chete Safari Area and the whole of the Sijarira Forest Area. Here, a mosaic of varied vegetation occurs with *Colophospermum mopane* and *Julbernardia globiflora* in alternating single dominance. Many of the soils in this area are shallow with low trees of *Colophospermum mopane* and occasional bushes of *Boscia* species. On higher levels, woodlands of *Julbernardia globiflora* occur with other trees and a well-developed shrub layer comprised of *Combretum* spp. and *Baphia massiensis.* Similar vegetation occurs on Karoo sandstones west of Kariangwe Mission in the south of the study area.

CLASS 9. COMPLEX OF *GUIBOURTIA CONJUGATA* AND *COMBRETUM* SPECIES

Dense thickets of *Combretum* spp. with trees of *Guibourtia conjugata* and a poorly developed grass layer, are found on the Kalahari sand deposits in the Manjolo Communal Land east of Binga (Figure 22). The shrub layer includes *Baphia massiensis* subsp. *obovata* and the tree layer, *Strychnos madagascariensis, Xeroderris stuhlmannii* and *Pterocarpus lucens* subsp. *antunesii* (Appendix 2).

CLASS 10. MIXED WOODLAND ON LOWER HILLS

On the rolling hills of Karoo sandstone, which typify the area between the lakeshore and the Kalahari sands in the Binga area (Figure 13), the vegetation complex is similar to that in Class 9, but has a greater variety of tree species and a less dense shrub layer (Appendix 2) (Figure 23). There is a gradation to *Colophospermum mopane* woodland (Table 4, Class 5) in flatter areas.

CLASS 11. MIXED WOODLAND ON ESCARPMENTS

Vegetation on escarpments throughout the study area is characterized by a mixed woodland with an open shrub layer (Figure 24). At lower altitudes, trees such as *Colophospermum mopane* and *Guibourtia conjugata* are mixed with *Diplorhyncus condylocarpon, Kigelia africana* and *Kirkia acuminata,* while at higher altitudes, *Julbernardia globiflora, Brachystegia glaucescens* and *Brachystegia boehmii* occur. The trees are consistently taller in Class 11 than those seen elsewhere in the study area, probably because there has been less disturbance of the vegetation on the escarpments.

CLASS 12. MIOMBO WOODLAND WITH *BRACHYSTEGIA BOEHMII* AND *JULBERNARDIA GLOBIFLORA*

Open woodlands dominated by *Brachystegia boehmii* and *Julbernardia globiflora* occupy most of the Chizarira Plateau and other higher areas, such as the Mapongola Hills (Figure 25). These miombo woodlands often have many other species in the lower tree and shrub layers (Appendix 2), and where the soils are heavier or where drainage is poorer, patches of *Colophospermum mopane* occur (Table 4, Class 5).

On the Chizarira Plateau, there are signs of regeneration of miombo woodland in areas which had been disturbed by elephants, although the *Brachystegia boehmii* and *Julbernardia globiflora* trees are smaller than in the undamaged areas (Figure 26). On the Plateau, the shrub layer is absent in many places, probably due to frequent burning (R. Drummond, pers. comm.).

CLASS 13. RIVERINE WOODLAND

Riverine woodlands fringe many of the watercourses in the study area. Usually there is a narrow band of trees with a well-developed shrub layer, although occasionally, a more extensive open woodland occurs with only a few shrubs (e.g. in the open *Acacia* woodland of the Sebungwe valley, northwest of Kariangwe Mission (Figure 27)). Elsewhere, the species are more mixed (Appendix 2).

CLASS 14. FIRE-AFFECTED AREA

Areas which have been recently affected by fire, before the regrowth described in Class 4 occurs, appear as bare soil on the satellite image. They are distinguished from other areas of bare soil by the patterns of the fire scars, which often cease abruptly at natural fire breaks, such as roads or rivers, or follow the topography in lines around hillsides.

CLASS 15. BARE SOIL AREA OF UNIDENTIFIED ORIGIN

Several areas on the satellite image, which had the spectral response of bare soil, could not be readily classified as cultivated or fire-affected (Table 4, Classes 1 and 14). Many of these areas are around the lakeshore, and represent dried grassland or bare soil exposed by changing lake levels.

Conclusions

The principal objective of Phase 1 of this work was to establish a baseline land use and vegetation classification for the study area, which would provide the framework within which historical changes in land use and vegetation cover could be quantified. The overriding influence of geology and soils on the reflectance values derived from the satellite image meant that ground surveys were essential to validate the image intepretation, and a manual interpretation of the image had to be undertaken. The API of two parts of the study area with contrasting topography, geology and human settlement patterns also confirmed the close association between the vegetation and land-use classes and underlying geomorphology and soils.

The major problem facing efforts to assess vegetation types in semi-arid and arid regions from satellite imagery is the effects of soil background on overall spectral response in areas of sparse vegetation cover. Matheson and Ringrose (1994) and Cherlet and Di Gregorio (1991), working in semi-arid and arid regions of Australia and the Sahel respectively, comprehensively demonstrated the need to compile as much basic ground-based information as possible in order to develop an integrated geo-referenced database with which to calibrate satellite-derived data (Gondo and Traub, 1993; Timberlake *et al.* 1993). Background information integrated in a GIS proved essential in refining image classification and vegetation class definition. For example, a GIS coverage of administrative boundaries, delimiting Communal Lands, National Parks, Forest and Safari Areas, enabled bare soil areas to be classified into classes 1, 14 or 15 according to whether human activity was permitted in the administrative area.

Environmental data, particularly rainfall figures, also provide essential background information for the interpretation of the land use and vegetation patterns in regions of predominantly rainfed agriculture. Although there was broad agreement in the areas delimited as human-dominated land use between the API and the satellite imagery, there was some indication that the area estimation from the 1992 satellite image was greater than from the 1990 aerial photography. This may be a function of the accuracy with which areas can be defined at different scales, but may also reflect the effects of the 1991/92 drought with larger areas of overgrazing and bare soil in settled areas. This will be investigated further in Phase 2.

Fifteen land-use and vegetation classes have been defined and quantified in an 8500 km^2 area adjacent to Lake Kariba, four of which relate to human land use, bare soil and the effects of fire. Seven dates have been selected for the historical study of land use/vegetation change from the Landsat TM and MSS images archives at EOSAT (Earth Observation Satellite Company) and in the Republic of South Africa. These are: 30 September 1972 (MSS, EOSAT), 3 September 1976 (MSS, EOSAT), 17 November 1980 (MSS, EOSAT), 22 July 1984 (TM, EOSAT), 12 July 1986 (MSS, RSA), 20 July 1989 (MSS, TM, RSA), 27 May 1993 (TM, RSA). These data will be used in the second phase of the study, in which particular emphasis will be given to the changing patterns and areas of human-dominated land use, as these will most closely reflect the impact of tsetse control, developmental and planning policies, and other social and economic factors that influence the agricultural development of the study area.

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Appendices

APPENDIX 1: VEGETATION SPECIES OR LAND USE IDENTIFIED AT FIELD SURVEY SITES

Class 1. Human land use dominant over natural vegetation

Dry-season survey sites

Site 3	airfield
Site 15	cultivated and grazed; many goats, some cattle
Site 20	grazing
Site 49	millet
Site 52	maize and settlement
Site 74	airstrip
Site 75	millet
Site 96	cultivation and vegetables
Site 100	cattle
Site 111	cultivation, vegetables and cattle
Site 128	cattle, goats and fishing
Site 131	settlement and cultivation
Site 132	cultivation and grazing
Site 137	settlements and cultivation
Site 150	new dam construction
Site 155	dam
Site 160	cultivated
Site 163	square field
Site 171	cotton
Site 177	airstrip
Site 178	settlement
Site 186	maize
Site 187	cultivated settlement
Site 189	cotton
Site 198	road
Site 208	road
Site 210	sewerage works

Wet-season survey sites

Site 2	industrial buildings
Site 15	maize and settlement
Site 16	maize and sorghum
Site 23	millet and settlement
Site 29	maize and settlement
Site 31	airstrip
Site 58	millet

Site 62	crops, vegetables and cattle
Site 64	cattle
Site 75	crops, grazing and settlement
Site 101	cattle, goats and fishing

Class 2. Grasses in well-watered areas

Dry-season survey sites

Site 64	grass along river banks; riverbed damp
Site 81	River Mucheni; *Phragmites australis*
Site 94	Mantizula Spring; raised swamp
Site 124	*Hyperrhenia* sp.
Site 146	grass along river banks; water in river
Site 179	flood plain
Site 191	Sengwa River; reed beds

Wet-season survey sites

Site 6	sulphur spring
Site 22a	valley grasslands
Site 25	valley grasslands
Site 80	grassland
Site 99	marsh grassland, palms

Class 3. Grasses around lakes and dams

Wet-season survey sites

Site 1	marsh, sedges
Site 5	tall grasslands
Site 26	*Panicum* sp., sedges
Site 54	grassland at edge of lake, *Agrotis* sp.

Class 4. Grasses regrowing after burning

Dry-season survey sites

Site 92	recent burn; fresh grass growth
Site 93	fresh *Aristida* sp.
Site 118	recent burn; fresh grass growth
Site 126	fresh grass growth

Wet-season survey sites

Site 24	grassland, burning
Site 50	charcoal evident

Class 5. *Colophospermum mopane* woodland

Dry-season survey sites

Site 9	*Colophospermum mopane*
Site 12	*Diplorhyncus condylocarpon, Colophospermum mopane, Strychnos madagascariensis*
Site 17	*Colophospermum mopane, Combretum* sp.
Site 19	*Colophospermum mopane*
Site 21	*Colophospermum mopane*
Site 22	*Colophospermum mopane*
Site 23	*Colophospermum mopane*

Site 27	*Colophospermum mopane*
Site 28	*Colophospermum mopane, Combretum* sp., *Guibourtia conjugata*
Site 30	*Acacia* spp., *Colophospermum mopane, Guibourtia conjugata*
Site 33	*Colophospermum mopane, Combretum* spp., *Guibourtia conjugata, Kirkia acuminata, Strychnos madagascariensis*
Site 36	*Colophospermum mopane*
Site 37	*Colophospermum mopane*
Site 42	*Colophospermum mopane*
Site 43	*Colophospermum mopane*
Site 44	*Colophospermum mopane*
Site 46	*Colophospermum mopane*
Site 56	*Acacia* spp., *Colophospermum mopane*
Site 58	*Afzelia quanzensis, Colophospermum mopane, Combretum* spp.
Site 59	*Colophospermum mopane, Combretum* spp.
Site 60	*Colophospermum mopane*
Site 62	*Colophospermum mopane*
Site 65	*Colophospermum mopane*
Site 67	*Adansonia digitata, Colophospermum mopane, Combretum* spp., *Crossopteryx febrifuga, Julbernardia globiflora*
Site 69	*Colophospermum mopane*
Site 70	*Colophospermum mopane*
Site 71	*Colophospermum mopane*
Site 72	*Boscia* spp., *Colophospermum mopane*
Site 77	*Colophospermum mopane*
Site 79	*Colophospermum mopane*
Site 84	*Colophospermum mopane, Ximenia americana*
Site 87	*Colophospermum mopane*
Site 89	*Colophospermum mopane*
Site 99	*Colophospermum mopane*
Site 108	*Colophospermum mopane, Commiphora* spp.
Site 109	*Adansonia digitata, Colophospermum mopane*
Site 115	*Brachystegia glaucescens, Colophospermum mopane*
Site 125	*Colophospermum mopane*
Site 127	*Boscia mossambicensis, Colophospermum mopane, Combretum elaeagnoides, Commiphora caerulea, Gardenia resiniflua, Kigelia africana, Kirkia acuminata*
Site 147	*Colophospermum mopane, Commiphora* spp.
Site 151	*Boscia* sp., *Colophospermum mopane, Lannea* sp.
Site 153	*Boscia* sp., *Colophospermum mopane*
Site 161	*Acacia tortilis* subsp. *spirocarpa, Colophospermum mopane, Combretum elaeagnoides, Dichrostachys cinerea, Guibourtia conjugata*
Site 162	*Colophospermum mopane*
Site 164	*Colophospermum mopane, Combretum apiculatum, Diospyros mespiliformis, Diplorhyncus condylocarpon, Strychnos spinosa, Terminalia sericea*
Site 167	*Cassia abbreviata, Colophospermum mopane, Combretum apiculatum*
Site 170	*Acacia tortilis* subsp. *spirocarpa, Colophospermum mopane, Combretum imberbe, Lonchocarpus capassa*

Site 172	*Colophospermum mopane*
Site 173	*Colophospermum mopane*
Site 175	*Colophospermum mopane, Combretum apiculatum, Commiphora* spp., *Diospyros quiloensis, Kirkia acuminata*
Site 180	*Acacia nigrescens, Adansonia digitata, Colophospermum mopane, Commiphora* spp., *Xeroderris stuhlmannii*
Site 181	*Colophospermum mopane, Combretum* spp.
Site 182	*Colophospermum mopane*
Site 188	*Colophospermum mopane*
Site 190	*Colophospermum mopane, Terminalia* spp.
Site 200	*Colophospermum mopane*
Site 202	*Colophospermum mopane*
Site 205	*Colophospermum mopane*
Site 206	*Colophospermum mopane*
Site 209	*Colophospermum mopane, Combretum molle, Commiphora* spp., *Kigelia africana, Kirkia acuminata, Sclerocarya birrea, Strychnos madagascariensis, Xeroderris stuhlmannii*
Site 213	*Acacia galpinii, Acacia nigrescens, Colophospermum mopane*
Site 214	*Colophospermum mopane*
Site 216	*Colophospermum mopane, Combretum* spp.
Site 224	*Acacia* spp., *Colophospermum mopane*

Wet-season survey sites

Site 12	*Colophospermum mopane*
Site 22	*Acacia* spp., *Colophospermum mopane*
Site 32	*Boscia* spp., *Colophospermum mopane, Combretum zeyheri, Crossopteryx febrifuga, Diospyros quiloensis, Pericopsis angolensis, Strychnos madagascariensis, Acacia tortilis* subsp. *spirocarpa, Colophospermum mopane, Commiphora* spp., *Kirkia acuminata, Terminalia* spp.
Site 33	*Colophospermum mopane, Combretum zeyheri, Guibourtia conjugata, Diospyros quiloensis, Terminalia sericea*
Site 48	*Colophospermum mopane, Combretum zeyheri, Combretum* spp., *Commiphora* spp., *Diospyros quiloensis, Terminalia* spp.
Site 49	*Colophospermum mopane, Commiphora* spp., *Diospyros quiloensis, Kirkia acuminata, Terminalia* spp.
Site 56	*Acacia tortilis* subsp. *spirocarpa, Colophospermum mopane, Diospyros quiloensis, Guibourtia conjugata*
Site 57	*Colophospermum mopane, Combretum zeyheri, Crossopteryx febrifuga, Diospyros quiloensis, Guibourtia conjugata*
Site 59	*Colophospermum mopane, Combretum* spp., *Combretum zeyheri, Commiphora* sp., *Crossopteryx febrifuga, Diospyros quiloensis*
Site 63	*Colophospermum mopane, Combretum zeyheri, Diospyros quiloensis, Lannea discolor*
Site 68	*Colophospermum mopane, Combretum zeyheri, Diospyros quiloensis, Lannea discolor, Terminalia* spp.
Site 69	*Colophospermum mopane, Combretum zeyheri, Diospyros quiloensis, Lannea discolor*
Site 70	*Adansonia digitata, Colophospermum mopane, Combretum mossambicensis, Diospyros quiloensis, Kigelia africana, Lannea discolor, Terminalia* sp.
Site 72	*Acacia nigrescens, Adansonia digitata, Albizia* sp., *Colophospermum mopane, Combretum zeyheri, Dichrostachys cinerea, Diospyros quiloensis*

Site 73 *Colophospermum mopane, Combretum zeyheri, Commiphora* spp., *Crossopteryx febrifuga, Strychnos madagascariensis*

Site 85 *Adansonia digitata, Colophospermum mopane, Combretum zeyheri, Commiphora* sp., *Crossopteryx febrifuga, Diospyros quiloensis, Kirkia acuminata, Strychnos madagascariensis, Terminalia* sp.

Site 87 *Colophospermum mopane, Combretum zeyheri*

Site 95 *Acacia tortilis* subsp. *spirocarpa, Colophospermum mopane, Combretum* sp., *Diospyros quiloensis, Kirkia acuminata*

Site 98 *Acacia tortilis* subsp. *spirocarpa, Colophospermum mopane, Commiphora caerulea, Ximenia americana*

Class 6. Woodland with *Julbernardia globiflora*

Dry-season survey sites

Site 66 *Julbernardia globiflora*, other mixed species

Site 83 *Julbernardia globiflora*

Site 176 *Julbernardia globiflora*, other mixed species

Site 212 *Combretum imberbe, Diospyros quiloensis, Diplorhyncus condylocarpon, Julbernardia globiflora, Sclerocarya birrea, Strychnos madagascariensis, Xeroderris stuhlmannii*

Site 218 *Burkea africana, Diplorhyncus condylocarpon, Julbernardia globiflora, Pterocarpus angolensis, Vitex mombassae*

Site 223 *Colophospermum mopane, Combretum imberbe, Julbernardia globiflora*

Wet-season survey sites

Site 21 *Burkea africana, Diplorhyncus condylocarpon, Julbernardia globiflora, Pseudolachnostylis maprouneifolia, Strychnos madagascariensis*

Site 34 *Baphia massiensis* subsp. *obovata, Colophospermum mopane, Combretum zeyheri, Diospyros kirkii, Diospyros quiloensis, Hippocratea parviflora, Holmskioldia tettensis, Julbernardia globiflora, Strychnos madagascariensis*

Site 39 *Combretum* spp., *Julbernardia globiflora, Lannea discolor, Pseudolachnostylis maprouneifolia*

Site 42 *Combretum zeyheri, Commiphora mossambicense, Diplorhyncus condylocarpon, Julbernardia globiflora, Kirkia acuminata, Lannea discolor, Strychnos madagascariensis, Strychnos spinosa*

Site 77 *Bauhinia petersiana* subsp. *petersiana, Combretum zeyheri, Crossopteryx febrifuga, Diospyros quiloensis, Diplorhyncus condylocarpon, Julbernardia globiflora, Kigelia africana, Kirkia acuminata, Strychnos madagascariensis*

Site 79 *Burkea africana, Combretum zeyheri, Commiphora* sp., *Diplorhyncus condylocarpon, Julbernardia globiflora, Lannea discolor, Pterocarpus angolensis, Xeroderris stuhlmannii*

Site 81 *Brachystegia* spp., *Colophospermum mopane, Combretum zeyheri, Julbernardia globiflora, Sclerocarya birrea, Terminalia sericea*

Site 96 *Combretum zeyheri, Julbernardia globiflora, Pseudolachnostylis maprouneifolia, Xeroderris stuhmannii*

Class 7. Woodlands with dense *Combretum* spp. shrubs

Dry-season survey sites

Site 7 *Combretum* spp.

Site 18	*Combretum* spp.
Site 55	*Baphia massiensis* subsp. *obovata, Brachystegia spiciformis, Burkea africana, Crossopteryx febrifuga, Combretum* spp., *Strychnos madagascariensis*
Site 68	*Colophospermum mopane, Combretum* spp.
Site 73	*Combretum* spp., *Julbernardia globiflora*
Site 82	*Combretum collinum, Combretum imberbe, Combretum molle, Diospyros kirkii, Lonchocarpus capassa, Xeroderris stuhlmannii*
Site 86	*Brachystegia boehmii, Combretum molle, Lannea discolor*
Site 98	*Boscia* sp., *Combretum apiculatum, Combretum elaeagnoides, Markhamia zanzibarica*
Site 110	*Baphia massiensis* subsp. *obovata, Combretum collinum, Combretum elaeagnoides, Lannea schweinfurthii, Pteleopsis anisoptera*
Site 112	*Baphia massiensis* subsp. *obovata, Combretum* spp.
Site 129	*Baphia massiensis* subsp. *oborata, Combretum collinum, Bauhinia petersiana* subsp. *petersiana, Combretum elaeagnoides, Diospyros quiloensis, Quibourtia conjugata, Pteleopsis myrtifolia, Strychnos madagascariensis*
Site 130	*Baphia massiensis* subsp. *obovata, Combretum* spp.
Site 136	*Acacia tortilis* subsp. *spirocarpa, Combretum apiculatum, Combretum elaeagnoides, Diplorhyncus condylocarpon, Strychnos madagascariensis, Terminalia prunioides*
Site 140	*Combretum elaeagnoides*
Site 145	*Combretum apiculatum, Combretum elaeagnoides*
Site 184	*Acacia* spp., *Combretum* spp.
Site 203	*Baphia massiensis* subsp. *obovata, Colophospermum mopane, Combretum apiculatum, Commiphora* sp., *Diospyros quiloensis, Strychnos madagascariensis, Xeroderris stuhlmannii*
Site 204	*Combretum* spp.
Site 207	*Combretum* spp.
Site 211	*Combretum* spp., *Julbernardia globiflora*

Wet-season survey sites

Site 8	*Albizia brevifolia, Combretum zeyheri, Commiphora mossambicense, Holmskioldia tettensis, Markhamia zanzibarica, Pterocarpus angolensis*
Site 51	*Baphia massiensis* subsp. *obovata, Combretum zeyheri, Diospyros quiloensis*
Site 93	*Combretum zeyheri, Diospyros quiloensis, Lannea discolor*

Class 9. Complex of *Guibourtia conjugata* and *Combretum* spp.

Dry-season survey sites

Site 8	*Acacia* sp., *Diospyros mespiliformis, Guibourtia conjugata, Strychnos madagascariensis*
Site 31	*Adansonia digitata, Combretum* spp., *Guibourtia conjugata*
Site 32	*Boscia mossambicensis, Combretum* spp., *Guibourtia conjugata*
Site 61	*Combretum* spp., *Guibourtia conjugata*
Site 63	*Combretum* spp., *Guibourtia conjugata*
Site 95	*Combretum celastroides, Combretum elaeagnoides, Guibourtia conjugata, Pterocarpus lucens* subsp. *antunesii, Strychnos madagascariensis*

Site 97 *Combretum apiculatum, Combretum elaeagnoides, Guibourtia conjugata, Lonchocarpus* sp., *Pterocarpus lucens* subsp. *antunesii, Strychnos madagascariensis, Boscia angustifolia* var. *corymbosa*

Site 152 *Combretum* spp., *Guibourtia conjugata, Lannea* sp.

Wet-season survey sites

Site 13 *Acacia tortilis* subsp. *spirocarpa, Adansonia digitata, Cassia abbreviata, Combretum zeyheri, Guibourtia conjugata, Lannea* spp.

Site 14 *Strychnos madagascariensis, Combretum zeyheri, Commiphora* sp., *Guibourtia conjugata*

Site 18 *Combretum* sp., *Combretum zeyheri, Guibourtia conjugata, Lannea* sp.

Site 19 *Cassia abbreviata, Combretum zeyheri, Guibourtia conjugata, Pseudolachnostylis maprouneifolia, Strychnos madagascariensis*

Site 35 *Acacia nigrescens, Colophospermum mopane, Combretum* sp., *Crossopteryx febrifuga, Diospyros quiloensis, Guibourtia conjugata, Holmskioldia tettensis, Pterocarpus angolensis, Strychnos madagascariensis*

Site 36 *Baphia massiensis* subsp. *obovata, Colophospermum mopane, Combretum* sp., *Dichrostachys cinerea, Guibourtia conjugata*

Site 47 *Baphia massiensis* subsp. *obovata, Combretum zeyheri, Guibourtia conjugata*

Site 53 *Combretum zeyheri, Guibourtia conjugata, Diospyros quiloensis*

Site 60 *Combretum zeyheri, Diospyros quiloensis, Gardenia resiniflua, Guibourtia conjugata, Lannea discolor, Strychnos madagascariensis*

Site 66 *Acacia tortilis* subsp. *spirocarpa, Combretum zeyheri, Guibourtia conjugata, Lannea discolor*

Site 71 *Albizia brevifolia, Colophospermum mopane, Combretum* sp., *Combretum zeyheri, Commiphora* sp., *Diospyros quiloensis, Guibourtia conjugata, Kirkia acuminata, Terminalia* sp.

Site 89 *Combretum zeyheri, Guibourtia conjugata, Xeroderris stuhlmannii*

Site 92 *Acacia tortilis* subsp. *spirocarpa, Adansonia digitata, Colophospermum mopane, Combretum zeyheri, Commiphora mossambicense, Diospyros quiloensis, Guibourtia conjugata, Kirkia acuminata, Lannea discolor, Strychnos madagascariensis, Terminalia* sp.

Site 97 *Combretum zeyheri, Guibourtia conjugata, Diospyros quiloensis*

Site 100 *Baphia massiensis* subsp. *obovata, Combretum zeyheri, Crossopteryx febrifuga, Guibourtia conjugata, Strychnos madagascariensis, Xeroderris stuhlmannii*

Class 10. Mixed woodland on lower hills

Dry-season survey sites

Site 1 *Baphia massiensis* subsp. *obovata, Diplorhyncus condylocarpon, Combretum* sp., *Strychnos madagascariensis, Bauhinia petersiana* subsp. *petersiana*

Site 2 *Burkea africana, Ximenia caffra, Combretum* sp., *Diplorhyncus condylocarpon*

Site 35 *Colophospermum mopane, Guibourtia conjugata, Kigelia africana, Kirkia acuminata*

Site 48 *Colophospermum mopane, Combretum* sp., *Guibourtia conjugata, Kirkia acuminata, Pseudolachnostylis maprouneifolia, Strychnos madagascariensis*

Site 158	*Acacia eriocarpa, Crossopteryx febrifuga, Diospyros quiloensis, Diplorhyncus condylocarpon, Guibourtia conjugata, Strychnos madagascariensis*
Site 199	*Baphia massiensis* subsp. *obovata, Combretum apiculatum, Diospyros quiloensis, Julbernardia globiflora, Kigelia africana, Sclerocarya birrea, Strychnos madagascariensis*

Wet-season survey sites

Site 3	*Baphia massiensis* subsp. *obovata, Combretum* sp., *Combretum zeyheri, Commiphora* sp., *Crossopteryx febrifuga, Diplorhyncus condylocarpon, Strychnos madagascariensis, Bauhinia petersiana* subsp. *petersiana*
Site 4	*Acacia* sp., *Lannea* sp., *Baphia massiensis* subsp. *obovata, Colophospermum mopane, Combretum* sp., *Combretum zeyheri, Holmskioldia tettensis*
Site 17	*Cassia abbreviata, Combretum* sp., *Combretum zeyheri, Guibourtia conjugata, Lannea* sp.
Site 20	*Berchemia discolor, Colophospermum mopane, Combretum zeyheri, Guibortia conjugata, Kirkia acuminata, Lannea* sp.
Site 27	*Berchemia discolor, Cassia abbreviata, Combretum* sp., *Diospyros quiloensis*
Site 37	*Combretum* sp., *Combretum zeyheri, Diospyros quiloensis, Guibourtia conjugata*
Site 45	*Colophospermum mopane, Combretum zeyheri, Diospyros quiloensis, Guibourtia conjugata, Strychnos madagascariensis*
Site 52	*Combretum zeyheri, Diospyros quiloensis, Guibourtia conjugata, Lannea discolor, Strychnos madagascariensis*
Site 55	*Acacia nigrescens, Acacia tortilis* subsp. *spirocarpa, Combretum imberbe, Combretum zeyheri, Diospyros quiloensis, Lannea discolor, Piliostigma thoningii*
Site 61	*Combretum celastroides, Combretum zeyheri, Strychnos madagascariensis, Diospyros quiloensis, Guibourtia conjugata, Lannea discolor*
Site 90	*Combretum* sp., *Combretum mossambicensis, Combretum zeyheri, Diospyros quiolensis, Guibourtia conjugata, Holmskioldia tettensis, Strychnos madagascariensis*
Site 94	*Combretum* sp., *Commiphora mossambicense, Diospyros quiloensis, Guibourtia conjugata, Hippocratea parviflora, Lannea discolor, Xeroderris stuhlmannii*

Class 11. Mixed woodland on escarpments

Dry-season survey sites

Site 14	*Colophospermum mopane, Julbernardia globiflora, Kigelia africana*
Site 39	very mixed
Site 144	*Colophospermum mopane, Commiphora caerulea, Croton menyhartii, Diospyros quiloensis, Gardenia resiniflua, Guibourtia conjugata, Kirkia acuminata*
Site 154	*Acacia ataxacantha, Colophospermum mopane, Combretum elaeagnoides, Commiphora* sp., *Croton menyhartii, Diospyros quiloensis, Guibourtia conjugata, Kirkia acuminata*
Site 183	*Colophospermum mopane, Combretum apiculatum, Julbernardia globiflora, Crossopteryx febrifuga, Kigelia africana, Strychnos madagascariensis*

Wet-season survey sites

Site 7 *Acacia nigrescens, Colophospermum mopane, Commiphora* sp., *Kirkia acuminata, Lannea* sp.

Site 9 *Colophospermum mopane, Commiphora mossambicense, Holmskioldia tettensis, Sclerocarya birrea*

Site 10 *Combretum zeyheri, Commiphora* sp., *Diplorhyncus condylocarpon, Guibourtia conjugata*

Site 11 *Bauhinia petersiana* subsp. *petersiana, Burkea africana, Combretum zeyheri, Diplorhyncus condylocarpon, Pseudolachnostylis maprouneifolia*

Site 38 *Brachystegia boehmii, Combretum* sp., *Diospyros quiloensis, Diplorhyncus condylocarpon, Julbernardia globiflora, Kirkia acuminata, Pseudolachnostylis maprouneifolia, Sclerocarya birrea, Strychnos madagascariensis, Terminalia* sp., *Ximenia caffra*

Site 43 *Baphia massiensis* subsp. *obovata, Bauhinia petersiana* subsp. *petersiana, Combretum zeyheri, Commiphora* sp., *Diospyros kirkii, Diplorhyncus condylocarpon, Julbernardia globiflora, Strychnos madagascariensis, Terminalia sericea*

Site 76 *Combretum zeyheri, Commiphora mossambicense, Strychnos madagascariensis, Terminalia sericea, Xeroderris stuhlmannii*

Site 78 *Baphia massiensis* subsp. *obovata, Bauhinia petersiana* subsp. *petersiana, Combretum zeyheri, Diospyros kirkii, Diplorhyncus condylocarpon, Julbernadia globiflora, Kirkia acuminata, Strychnos spinosa, Terminalia sericea*

Class 12. Miombo woodland with *Brachystegia boehmi* and *Julbernardia globiflora*

Dry-season survey sites

Site 80 *Brachystegia spiciformis, Julbernardia globiflora*

Site 85 *Brachystegia spiciformis, Julbernardia globiflora*

Site 90 *Brachystegia boehmii, Combretum* sp., *Pseudolachnostylis maprouneifolia*

Site 91 *Brachystegia boehmii, Combretum* sp., *Pseudolachnostylis maprouneifolia*

Site 113 *Brachystegia glaucescens, Combretum zeyheri, Diplorhyncus condylocarpon, Hexalobus monopetalus, Julbernardia globiflora, Pseudolachnostylis maprouneifolia, Pteleopsis anisoptera, Vitex mombassae*

Site 117 *Brachystegia boehmii, Julbernardia globiflora*

Site 119 *Brachystegia* sp., *Burkea africana, Julbernardia globiflora, Pterocarpus* sp., *Terminalia* sp., *Ximenia caffra*

Site 123 *Brachystegia spiciformis, Julbernardia globiflora, Pseudolachnostylis maprouneifolia*

Site 219 *Brachystegia glaucescens, Julbernardia globiflora*

Site 221 *Brachystegia glaucescens, Julbernardia globiflora*

Wet-season survey sites

Site 40 *Brachystegia boehmii, Brachystegia glaucescens, Combretum* sp., *Combretum zeyheri, Commiphora mossambicense, Diplorhyncus condylocarpon, Julbernardia globiflora, Lannea discolor*

Site 41 *Bauhinia petersiana* subsp. *petersiana, Brachystegia* sp., *Combretum* sp., *Combretum zeyheri, Commiphora* *mossambicense, Crossopteryx febrifuga, Diospyros kirkii, Lannea discolor*

Site 82	*Brachystegia* sp., *Combretum zeyheri, Diplorhyncus condylocarpon, Julbernardia globiflora, Kigelia africana, Pseudolachnostylis maprouneifolia, Pterocarpus angolensis*
Site 83	*Brachystegia* sp., *Diplorhyncus condylocarpon, Julbernardia globiflora, Lannea discolor, Pseudolachnostylis maprouneifolia, Pterocarpus angolensis*

Class 13. Riverine woodland

Dry-season survey sites

Site 13	*Acacia galpinii, Colophospermum mopane, Combretum molle, Dichrostachys cinerea*
Site 25	*Colophospermum mopane, Combretum* spp.
Site 26	*Adansonia digitata, Combretum* spp.
Site 88	*Brachystegia boehmii, Piliostigma thoningii, Terminalia* sp., *Ziziphus abyssinica*
Site 98	*Afzelia quanzensis, Artabotrys brachypetalus, Lonchocarpus eriocalyx* subsp. *makieensis*
Site 101	*Acacia* spp.
Site 133	*Acacia* sp., *Acacia nigrescens, Adansonia digitata, Berchemia discolor*
Site 135	*Acacia nilotica, Acacia tortilis* subsp. *spirocarpa, Adansonia digitata, Cassia abbreviata, Dichrostachys cinerea, Diospyros quiloensis, Grewia bicolor*
Site 139	*Acacia nilotica, Acacia tortilis* subsp. *spirocarpa, Colophospermum mopane, Diospyros quiloensis, Gardenia resiniflua*
Site 201	*Afzelia quanzensis, Combretum molle, Combretum mossambicensis, Colophospermum mopane, Kirkia acuminata, Terminalia sericea, Tamarindus indica, Xeroderris stuhlmannii*
Site 215	*Acacia nilotica, Acacia tortilis* subsp. *spirocarpa, Combretum imberbe*
Site 220	*Julbernardia globiflora, Kirkia acuminata*

Wet-season survey sites

Site 28	*Baphia massiensis* subsp. *obovata, Berchemia discolor, Colophospermum mopane, Combretum* sp., *Combretum imberbe, Commiphora* sp., *Strychnos madagascariensis, Terminalia sericea*
Site 67	*Terminalia sericea, Acacia nigrescens, Acacia tortilis* subsp. *spirocarpa, Cassia abbreviata, Colophospermum mopane, Commiphora* sp., *Diospyros quiloensis, Kirkia acuminata*
Site 74	*Colophospermum mopane, Combretum imberbe, Combretum zeyheri, Diospyros quiloensis, Lonchocarpus capassa, Sclerocarya birrea*
Site 86	*Acacia nigrescens, Combretum* sp., *Combretum mossambicensis, Combretum zeyheri, Crossopteryx febrifuga, Terminalia sericea, Diospyros mespiliformis, Lannea discolor*

APPENDIX 2: SPECIES IDENTIFIED IN WOODLAND VEGETATION CLASSES (CLASSES 5 TO 13)

Class 5. *Colophospermum mopane* woodland

Acacia sp.
Acacia galpinii
Acacia nigrescens
Acacia tortilis subsp. *spirocarpa*
Adansonia digitata
Afzelia quanzensis
Albizia sp.
Boscia sp.
Boscia mossambicensis
Brachystegia glaucescens
Cassia abbreviata
Colophospermum mopane
Combretum sp.
Combretum apiculatum
Combretum elaeagnoides
Combretum imberbe
Combretum molle
Combretum zeyheri
Commiphora sp.
Commiphora caerulea
Crossopteryx febrifuga
Dichrostachys cinerea
Diospyros mespiliformis
Diplorhyncus condylocarpon
Gardenia resiniflua
Guibourtia conjugata
Julbernardia globiflora
Kigelia africana
Kirkia acuminata
Lannea sp.
Lannea discolor
Lonchocarpus capassa
Pericopsis angolensis
Sclerocarya birrea
Strychnos madagascariensis
Strychnos spinosa
Terminalia sericea
Xeroderris stuhlmannii
Ximenia americana

Class 6. Woodland with *Julbernardia globiflora*

Baphia massiensis subsp. *obovata*
Bauhinia petersiana subsp. *petersiana*
Brachystegia sp.
Burkea africana
Colophospermum mopane
Combretum sp.
Combretum imberbe
Combretum zeyheri
Commiphora sp.
Commiphora mossambicensis
Crossopteryx febrifuga
Diospyros kirkii
Diospyros quiloensis
Diplorhyncus condylocarpon
Hippocratea parviflora
Holmskioldia tettensis
Julbernardia globiflora
Kigelia africana
Kirkia acuminata
Lannea discolor
Pseudolachnostylis maprouneifolia
Pterocarpus angolensis
Sclerocarya birrea
Strychnos madagascariensis
Strychnos spinosa
Terminalia sericea
Vitex mombassae
Xeroderris stuhlmannii

Class 7. Woodlands with dense *Combretum* sp. shrubs

Acacia spp.
Acacia tortilis subsp. *spirocarpa*
Albizia brevifolia
Baphia massiensis subsp. *obovata*
Bauhinia petersiana subsp. *petersiana*
Boscia sp.
Brachystegia boehmii
Brachystegia spiciformis
Burkea africana
Colophospermum mopane
Combretum mossambicensis
Crossopteryx febrifuga
Diospyros kirkii
Diospyros quiloensis
Diplorhyncus condylocarpon
Guibourtia conjugata
Holmskioldia tettensis
Julbernardia globiflora
Lannea discolor
Lannea schweinfurthii

Combretum spp.
Combretum apiculatum
Combretum collinum
Combretum elaeagnoides
Combretum imberbe
Combretum molle
Combretum zeyheri
Commiphora sp.
Lonchocarpus capassa
Markhamia zanzibarica
Pteleopsis anisoptera
Pteleopsis myrtifolia
Pterocarpus angolensis
Strychnos madagascariensis
Terminalia prunioides
Xeroderris stuhlmannii

Class 9. Complex of *Guibourtia conjugata* and *Combretum* sp.

Acacia sp.
Acacia nigrescens
Acacia tortilis subsp. *spirocarpa*
Adansonia digitata
Albizia brevifolia
Baphia massiensis subsp. *obovata*
Boscia angustifolia var. *corymbosa*
Boscia mossambicensis
Cassia abbreviata
Colophospermum mopane
Combretum spp.
Combretum apiculatum
Combretum celastroides
Combretum elaeagnoides
Combretum zeyheri
Commiphora sp.
Combretum mossambicensis
Crossopteryx febrifuga
Dichrostachys cinerea
Diospyros mespiliformis
Diospyros quiloensis
Gardenia resiniflua
Guibourtia conjugata
Holmskioldia tettensis
Kirkia acuminata
Lannea sp.
Lannea discolor
Lonchocarpus sp.
Pseudolachnostylis maprouneifolia
Pterocarpus angolensis
Pterocarpus lucens subsp. *antunesii*
Strychos madagascariensis
Terminalia sp.
Xeroderris stuhlmannii

Class 10. Mixed woodland on lower hills

Acacia sp.
Acacia eriocarpa
Acacia nigrescens
Acacia tortilis subsp. *spirocarpa*
Baphia massiensis subsp. *obovata*
Bauhinia petersiana subsp. *petersiana*
Berchemia discolor subsp. *macrantha*
Burkea africana
Cassia abbreviata
Colophospermum mopane
Combretum sp.
Combretum apiculatum
Combretum celastroides
Combretum imberbe
Combretum zeyheri
Commiphora sp.
Crossopteryx febrifuga
Diospyros quiloensis
Diplorhyncus condylocarpon
Guibourtia conjugata
Hippocratea parviflora
Holmskioldia tettensis
Julbernardia globiflora
Kigelia africana
Kirkia acuminata
Lannea sp.
Lannea discolor
Piliostigma thoningii
Pseudolachnostylis maprouneifolia
Sclerocarya birrea
Strychnos madagascariensis
Ximenia caffra

Class 11. Mixed woodland on escarpments

Acacia ataxacantha
Acacia nigrescens
Baphia massiensis subsp. *obovata*
Bauhinia petersiana subsp. *petersiana*
Brachystegia boehmii
Burkea africana
Colophospermum mopane
Diplorhyncus condylocarpon
Gardenia resiniflua
Guibourtia conjugata
Julbernardia globiflora
Holmskioldia tettensis
Kigelia africana
Kirkia acuminata

Combretum apiculatum
Combretum elaeagnoides
Combretum zeyheri
Commiphora sp.
Commiphora caerulea
Combretum mossambicensis
Crossopteryx febrifuga
Croton menyhartii
Diospyros kirkii
Diospyros quiloensis
Lannea sp.
Pseudolachnostylis maprouneifolia
Sclerocarya birrea
Strychnos madagascariensis
Strychnos spinosa
Terminalia sp.
Terminalia sericea
Xeroderris stuhlmannii
Ximenia caffra

Class 12. Miombo woodland with *Brachystegia boehmii* and *Julbernardia globiflora*

Bauhinia petersiana subsp. *petersiana*
Brachystegia sp.
Brachystegia boehmii
Brachystegia glaucescens
Brachystegia spiciformis
Burkea africana
Combretum sp.
Combretum zeyheri
Combretum mossambicensis
Crossopteryx febrifuga
Diospyros kirkii
Diplorhyncus condylocarpon
Hexalobus monopetalus
Julbernardia globiflora
Kigelia africana
Lannea discolor
Pseudolachnostylis maprouneifolia
Pteleopsis anisoptera
Pterocarpus sp.
Pterocarpus angolensis
Terminalia sp.
Vitex mombassae
Ximenia caffra

Class 13. Riverine woodland

Acacia spp.
Acacia galpinii
Acacia nilotica
Acacia nigrescens
Acacia tortilis subsp. *spirocarpa*
Adansonia digitata
Afzelia quanzensis
Artabotrys brachypetalus
Baphia massiensis subsp. *obovata*
Berchemia discolor subsp. *macrantha*
Brachystegia boehmii

Cassia abbreviata
Colophospermum mopane
Combretum spp.
Combretum apiculatum
Combretum imberbe
Combretum molle
Combretum mossambicensis
Combretum zeyheri
Commiphora sp.
Crossopteryx febrifuga
Dichrostachys cinerea
Diospyros mespiliformis
Diospyros quiloensis
Gardenia resiniflua
Grewia bicolor
Julbernardia globiflora
Kirkia acuminata
Lannea discolor
Lonchocarpus capassa
Lonchocarpus eriocalyx subsp. *mankieensis*
Piliostigma thoningii
Sclerocarya birrea
Strychnos madagascariensis
Tamarindus indica
Terminalia sp.
Terminalia sericea
Xeroderris stuhlmannii
Ziziphus abyssinica

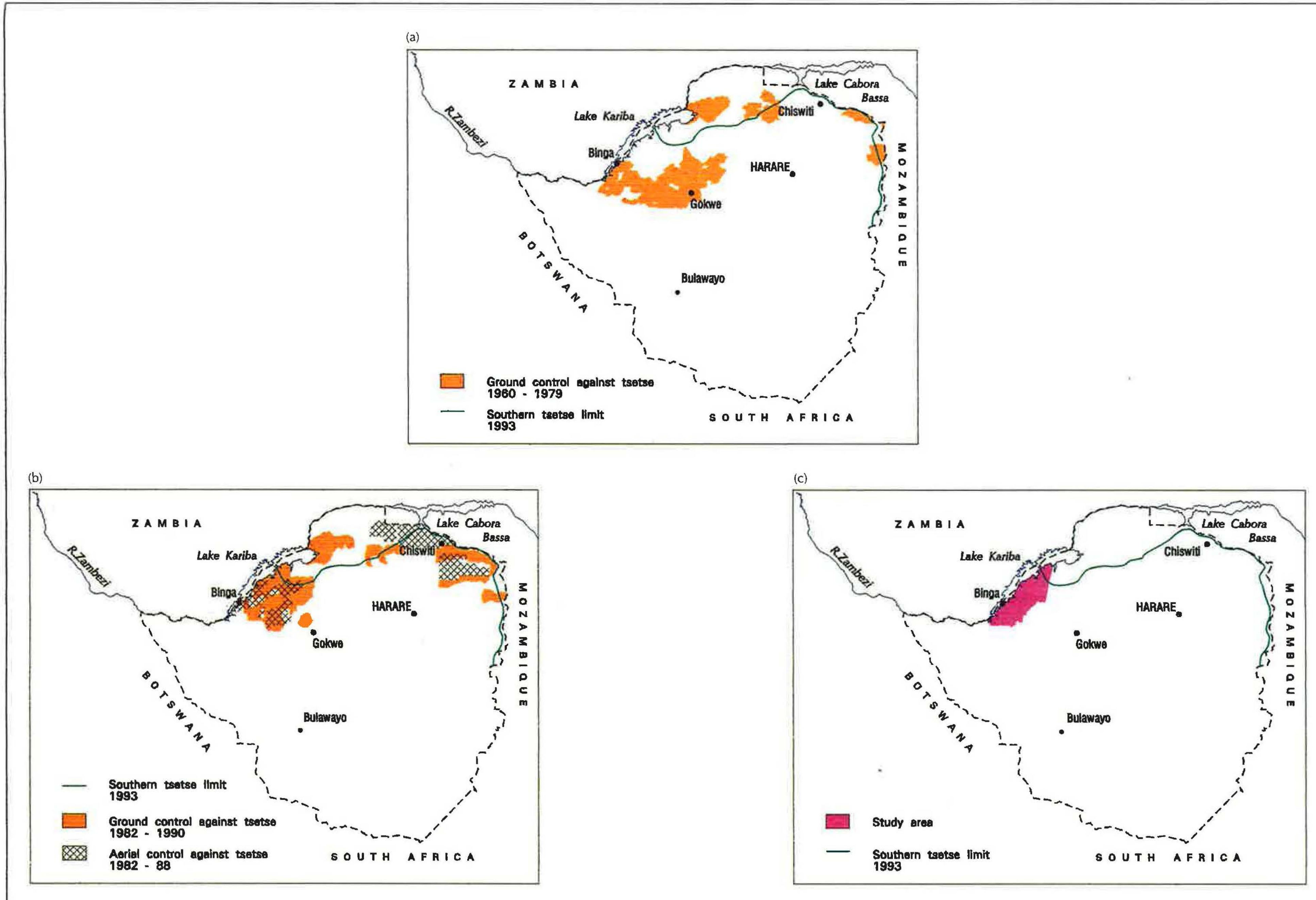

Figure 1 (a) Areas of ground control operations against tsetse in Zimbabwe 1960–1979; (b) Areas of ground (1980–1990) and aerial (1982–1988) control operations against tsetse; (c) Southern limit of tsetse in 1993 in Zimbabwe and the Lake Kariba study area

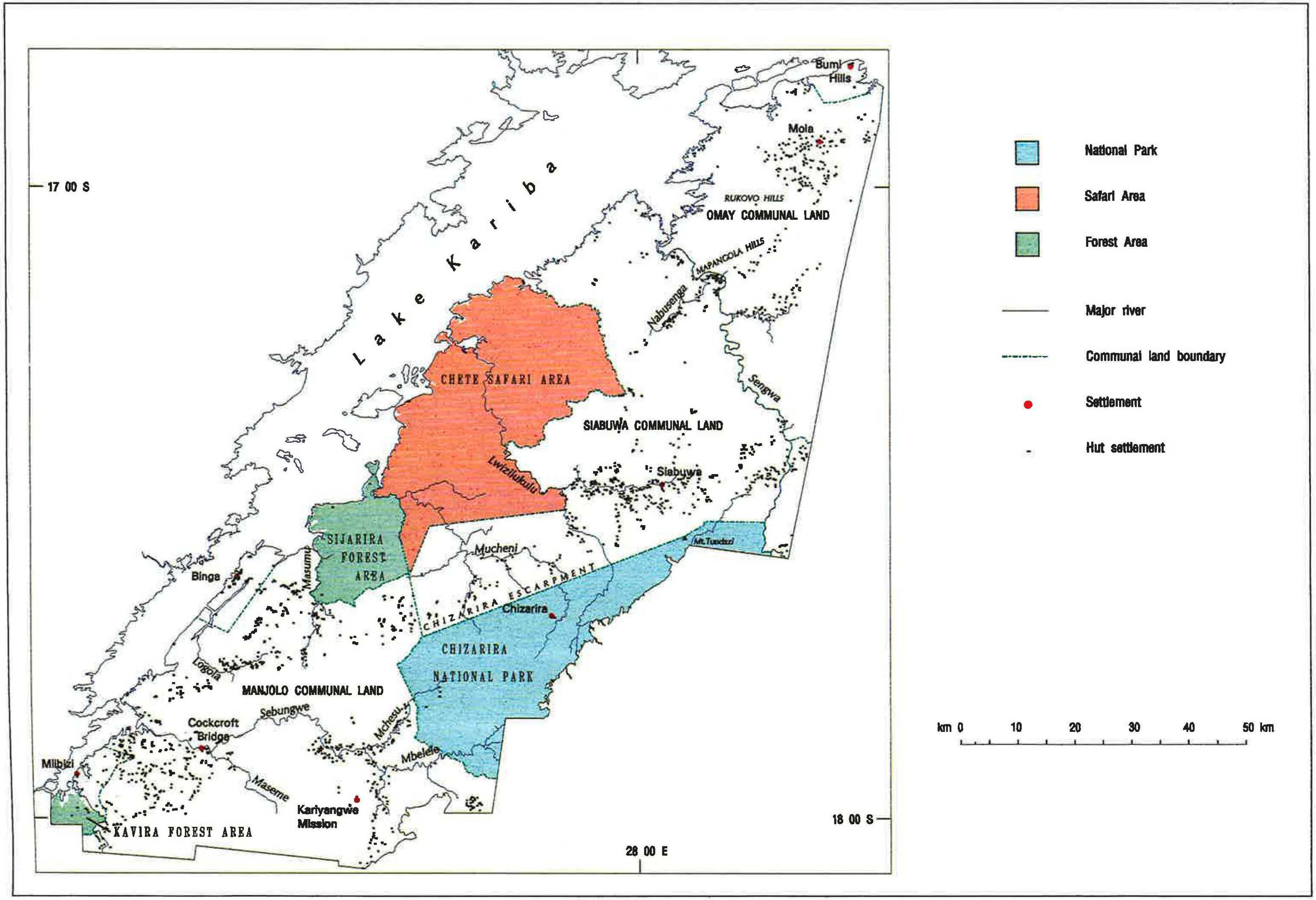

Figure 2 Lake Kariba study area

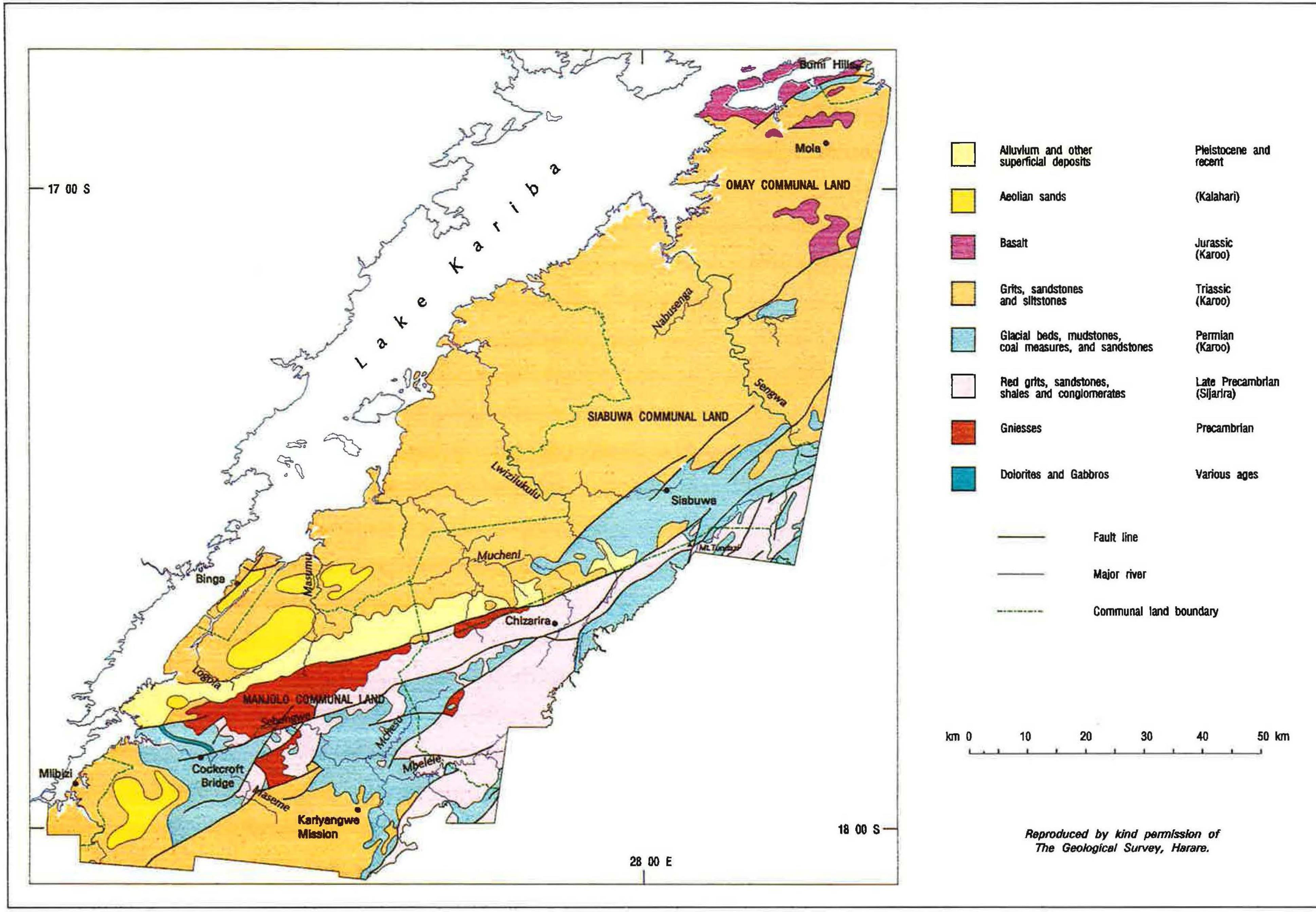

Figure 3 Geology of the study area

Figure 4 Gritstone pebbles on Triassic Karoo beds in Sijarira Forest Area (vegetation class 8) *Colophospermum mopane* (foreground) and *Julbernardia globiflora* (background) (dry-season survey site 60)

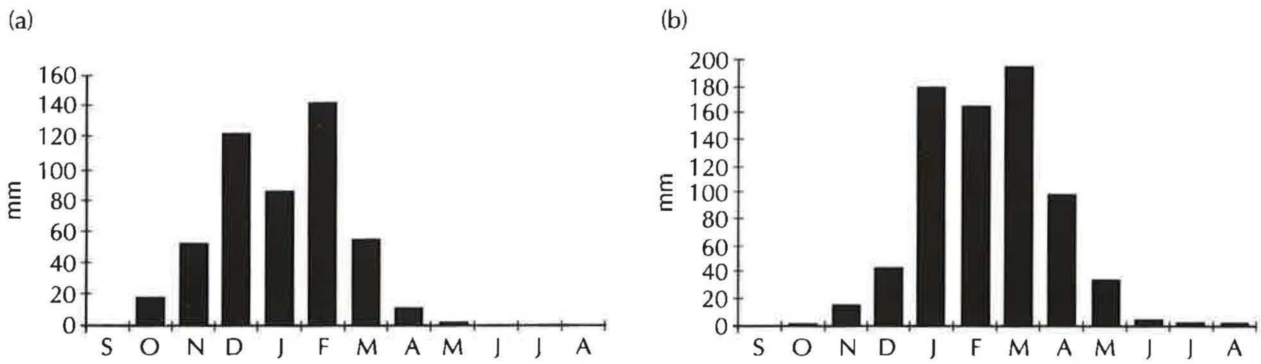

Figure 5 Average monthly rainfall at (a) Siabuwa and (b) Binga

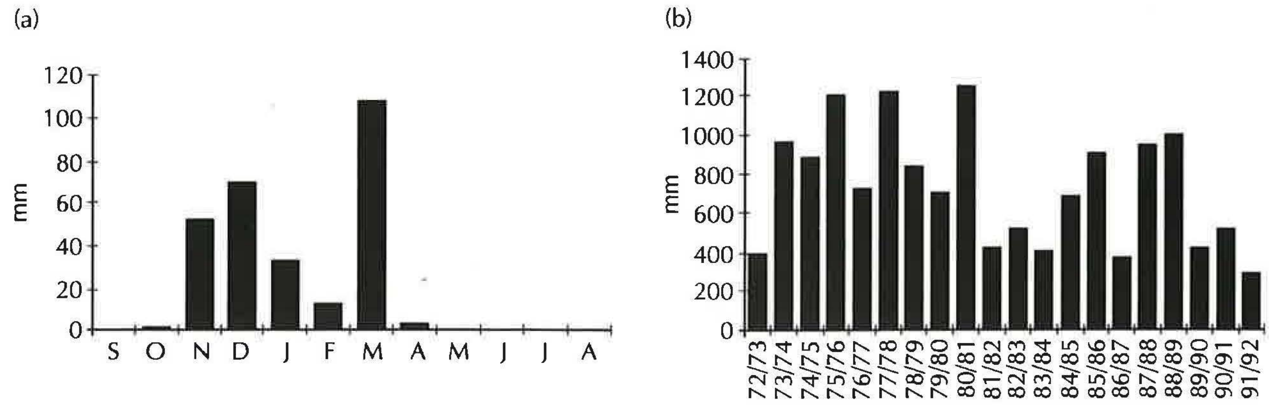

Figure 6 (a) Monthly rainfall (1991–1992) and (b) annual rainfall totals (1972–1992) at Binga

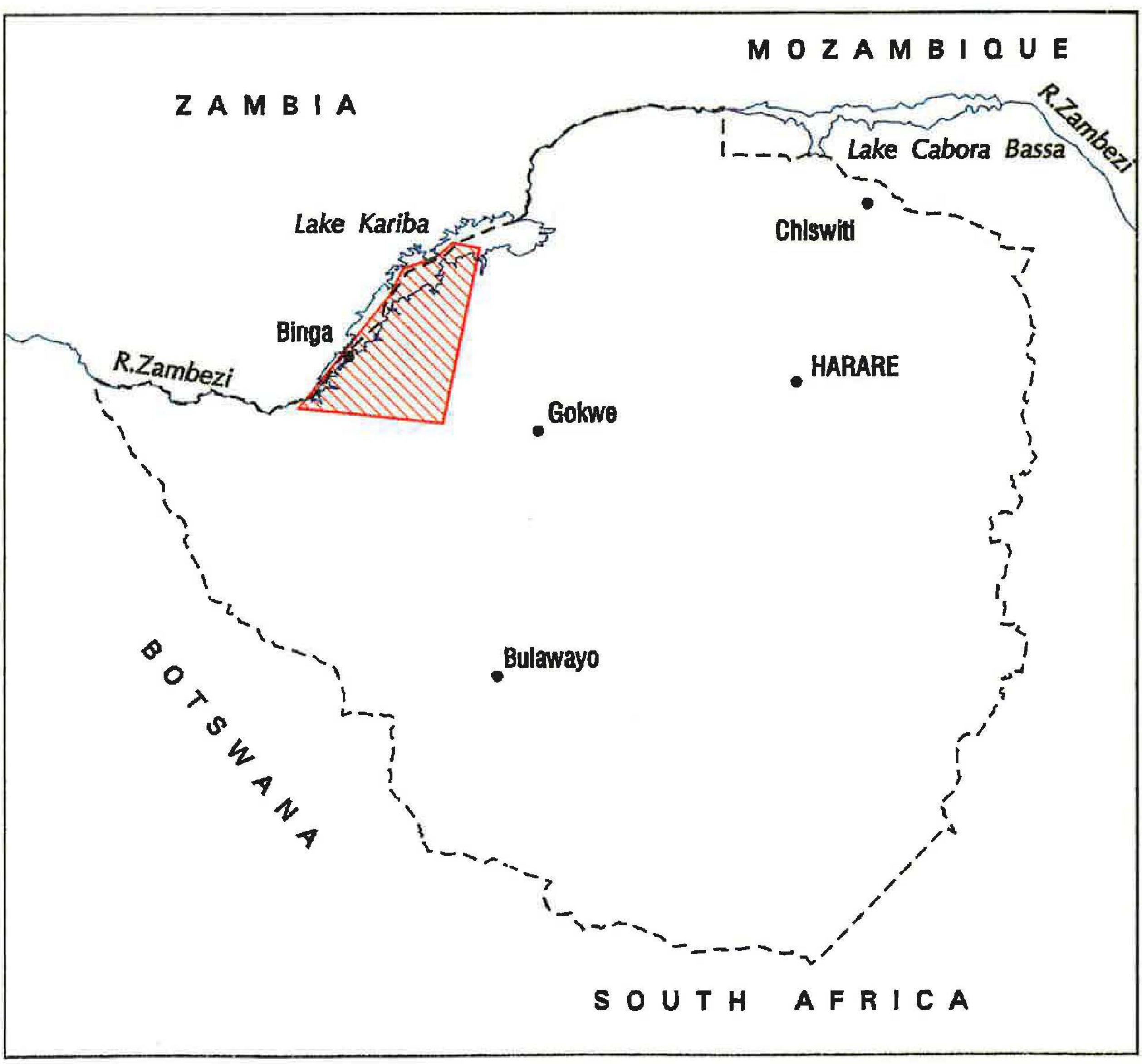

Figure 7 Area of Zimbabwe covered by Landsat Thematic Mapper scene 172/72

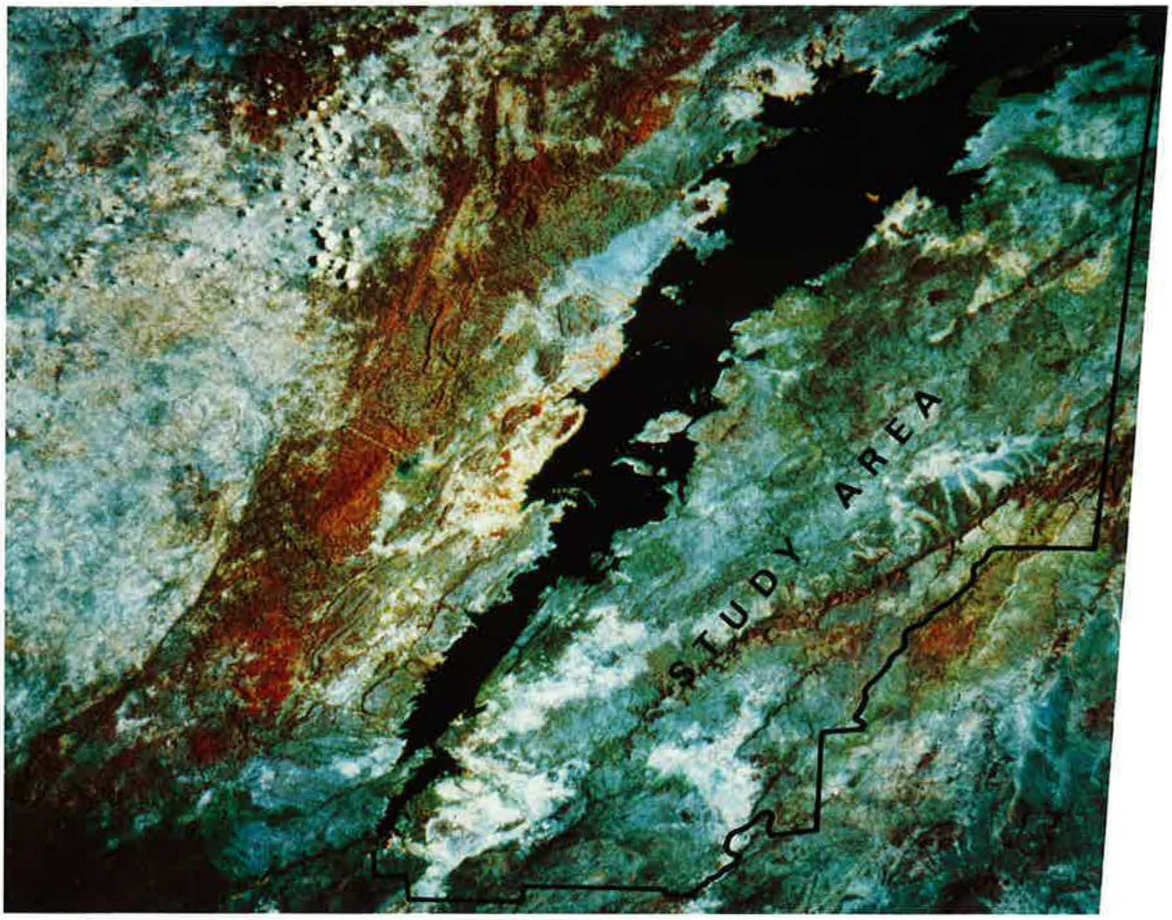

Figure 8 Landsat Thematic Mapper scene 172/72 for 19 February 1992

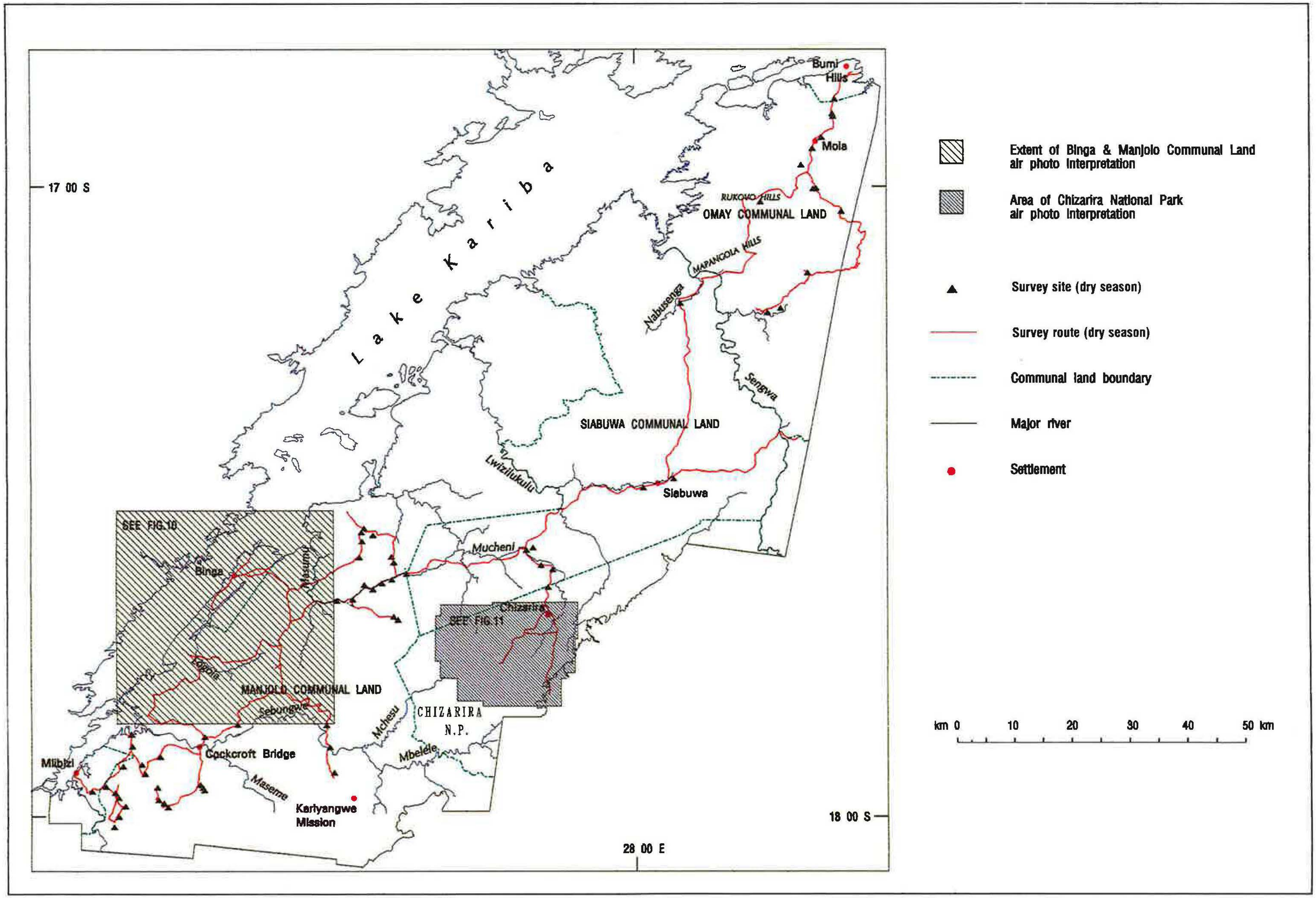

Figure 9 Areas covered by aerial photography and additional survey sites

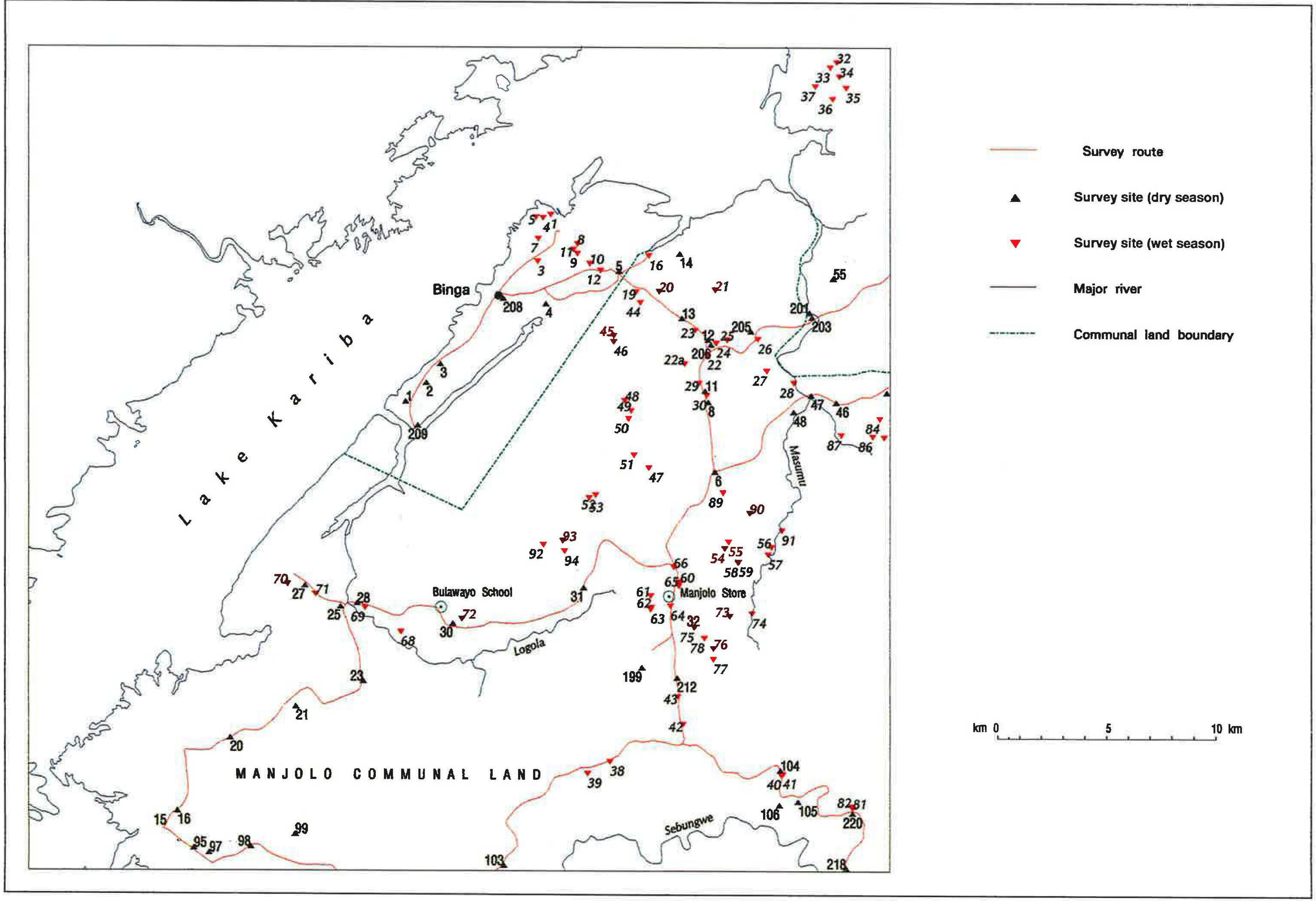

Figure 10 Survey route and sites in the Binga area and northern Manjolo Communal Land covered by API

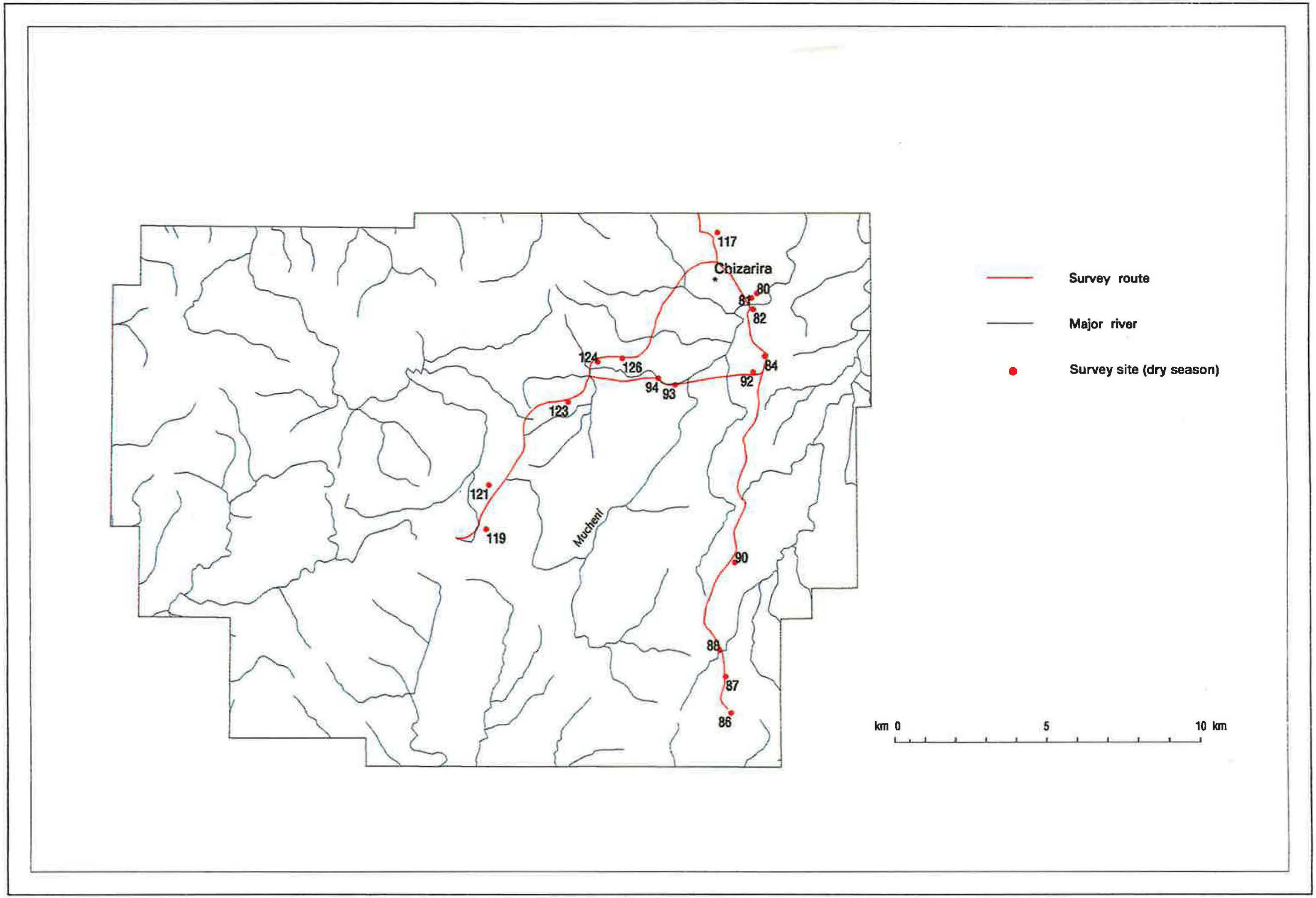

Figure 11 Survey route and sites in the Chizarira National Park covered by API

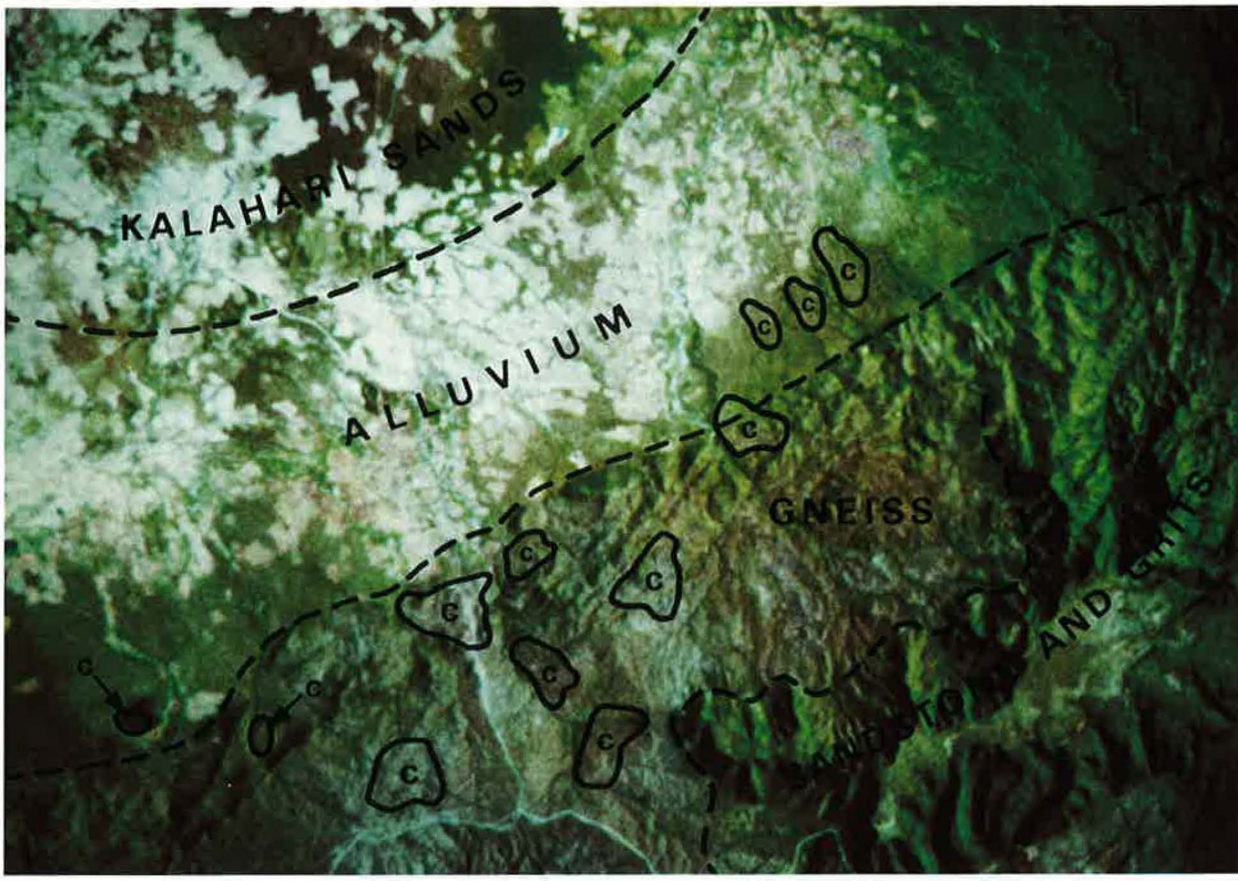

Figure 12 Thematic mapper image of area north of Cockcroft Bridge showing the effect of gneiss and gritstone on the reflectance of *Colophospermum mopane* woodland

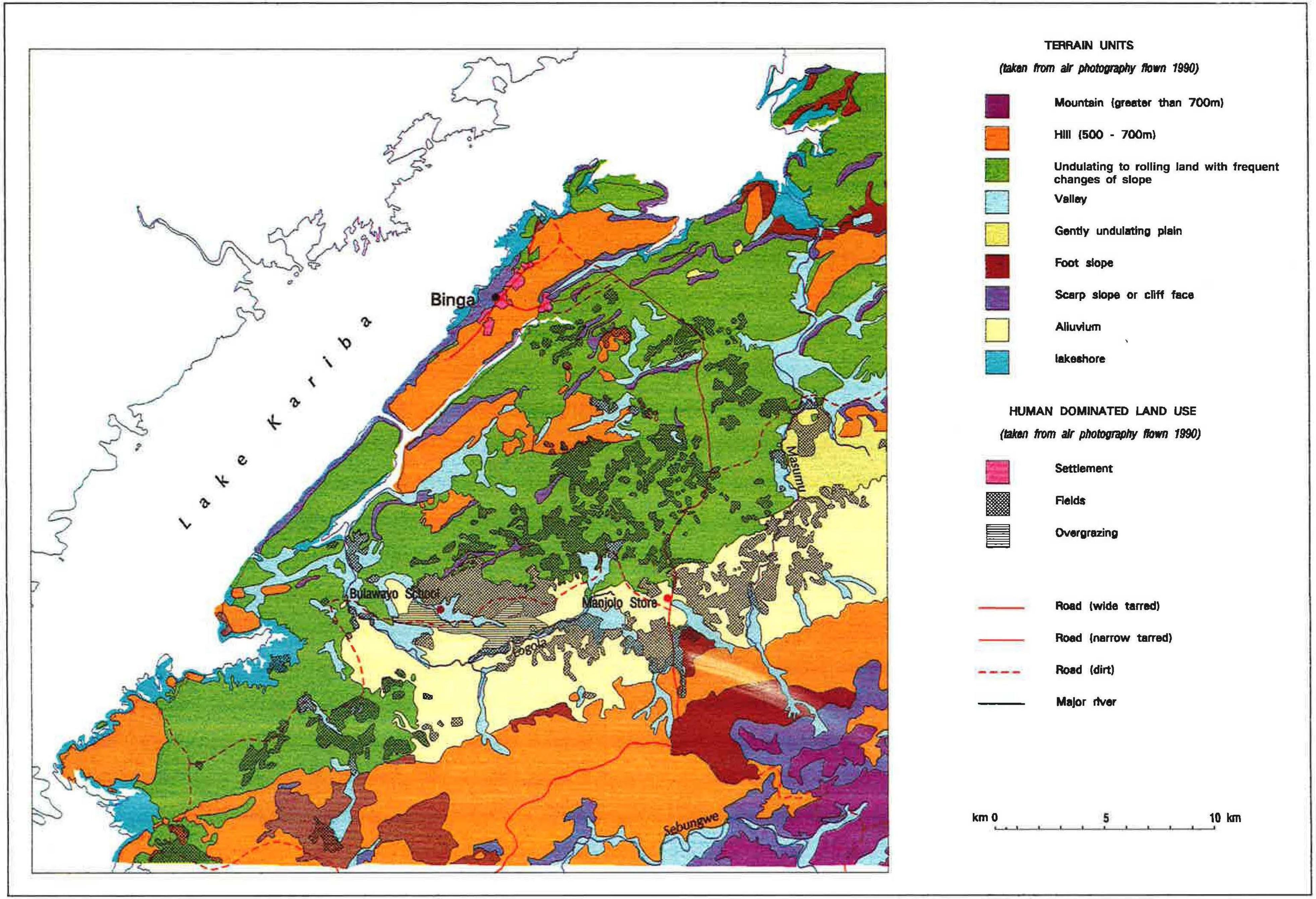

Figure 13 Terrain units and human-dominated land use in the Binga area and northern Manjolo Communal Land

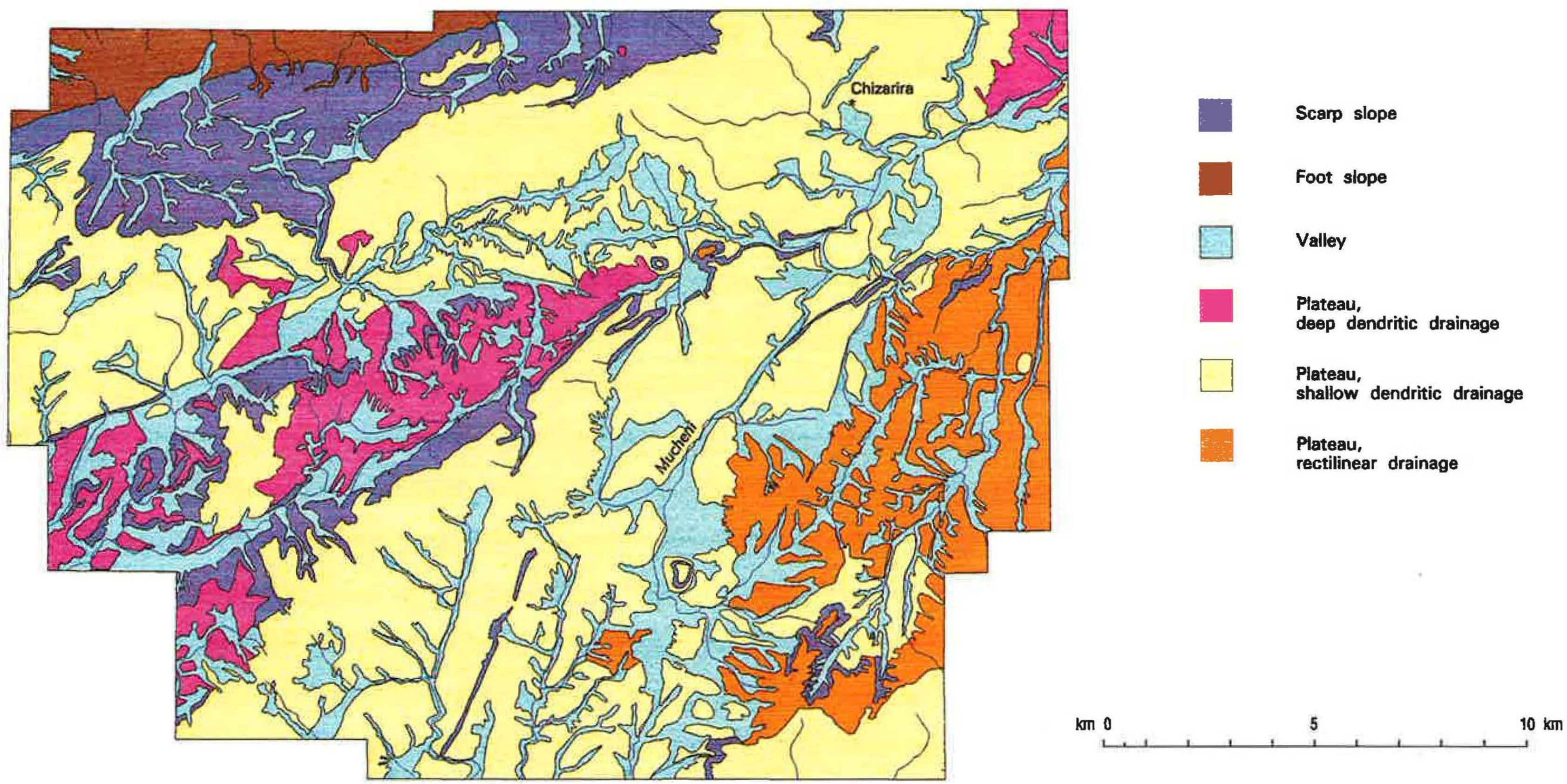

Figure 14 Terrain units in part of the Chizarira National Park

Figure 15 Vegetation Class 1. Human land use dominant in the northern Manjolo Communal Land (dry-season survey site 15)

Figure 16 Vegetation Class 2. Grasses in well-watered area around Manitzula Spring, Chizarira National Park (dry-season survey site 94)

Figure 17 Vegetation Class 3. Grasses around Lake Kariba, Sijarira Forest Area (wet-season survey site 54)

Figure 18 Vegetation Class 4. Grasses regrowing after burning in the Chizarira National Park (dry-season survey site 93)

Figure 19 Vegetation Class 5. *Colophospermum mopane* woodland in northern Manjolo Communal Land (dry-season survey site 46)

Figure 20 Vegetation Class 6. Woodland with *Julbernardia globiflora* in northern Manjolo Communal Land (dry-season survey site 218)

Figure 21 Vegetation Class 7. Woodland with dense *Combretum* sp. shrubs in Manjolo Communal Land (dry-season survey site 82)

Figure 22 Vegetation Class 9. Complex of *Guibourtia conjugata* and *Combretum* sp. shrubs in Manjolo Communal Land (dry-season survey site 32)

Figure 23 Vegetation Class 10. Mixed woodland on lower hills in the Binga area (dry-season survey site 1)

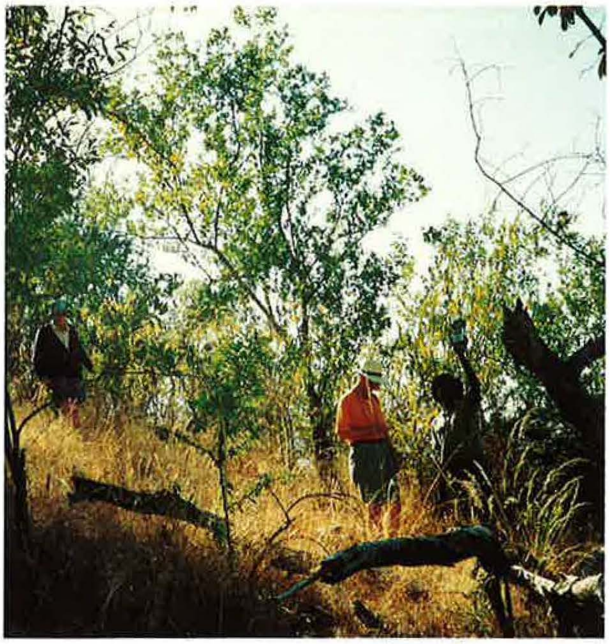

Figure 24 Vegetation Class 11. Mixed woodland on escarpments southwest of Cockcroft Bridge (dry-season survey site 144)

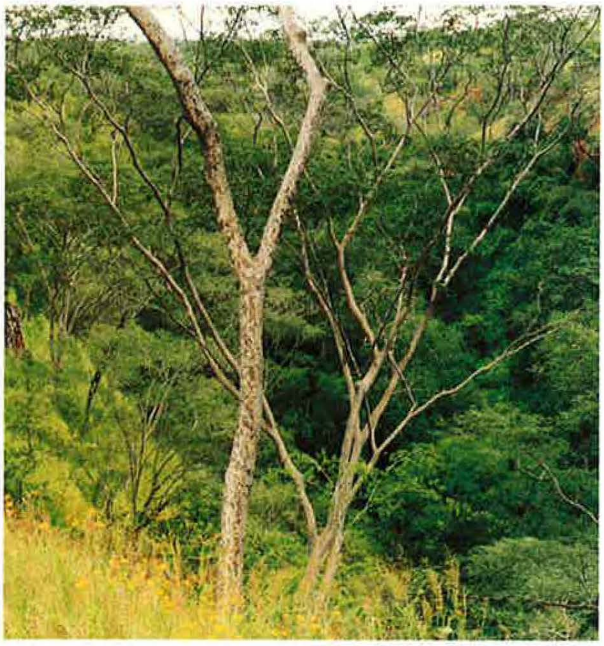

Figure 25 Vegetation Class 12. Miombo woodland with *Brachystegia boehmii* and *Julbernardia globiflora* in Manjolo Communal Land (wet-season survey site 82)

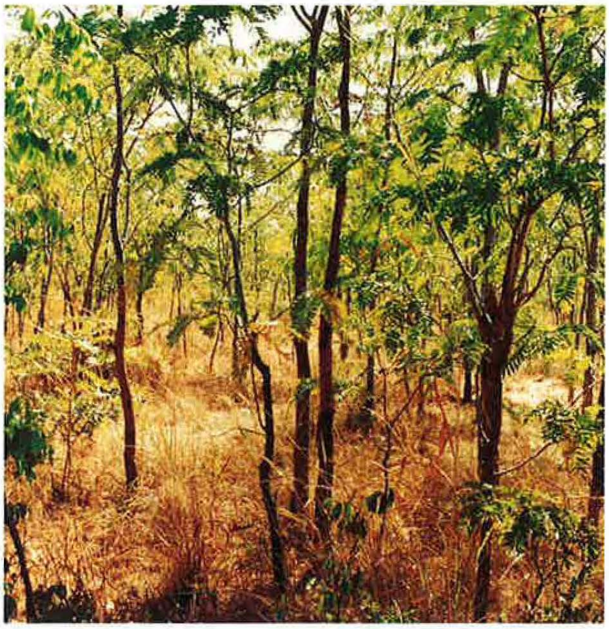

Figure 26 Vegetation Class 12. Miombo woodland regenerating in the Chizarira National Park (dry-season survey site 117)

Figure 27 Vegetation Class 13. Riverine woodland in the Sebungwe Valley (dry-season survey site 215)

In areas of Africa affected by trypanosomiasis, tsetse control is a major component of rural development activities. As part of an international programme of work in southern Africa, the effects of tsetse control on land use and vegetation change over a 20-year period are being assessed using satellite imagery.

Impact of Tsetse Control on Land Use in the Semi-Arid Zone of Zimbabwe. Phase 1: Classification of Land Use by Remote Sensing Imagery defines the baseline vegetation and land-use classes within a study area south of Lake Kariba in Zimbabwe. Black and white aerial photography and a Landsat TM image were used for the analysis. Fieldwork was carried out in both wet and dry seasons, and physical data were collected from more than 300 field sites. Fifteen land-use/vegetation classes were derived.

This publication provides maps and tables of the vegetation classes. Phase 2 of the study will quantify land use and vegetation change in relation to the history of tsetse-control operations in the area.