PATTERNS OF LAND COVER CHANGE IN KANYATI COMMUNAL LAND IN ZIMBABWE

by

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ABSTRACT

Expanding areas under cultivation and settlement are a global trend with significant effects on existing land cover types and ecosystems. High rates of human population growth in southern Africa and subsequent increased pressure on land has led to the extension of cultivation and settlement into marginal lands. This study investigates the spatial patterns of land cover change in a communal land in Zimbabwe over the period 1973 to 1993, and their likely ecological effects. The study site is in the Zambezi Valley and has a well-preserved area of miombo woodland and has the potential to become an important wildlife corridor between a national park, safari area and communal lands with local community based wildlife management projects. The area is divided into wildlife and settled areas by a game fence so provided an opportunity to compare patterns of land cover change with and without extensive human impact within the same administrative area.

The land cover types were derived from manually interpreted aerial photographs as multispectral satellite imagery is not available before the 1980's and is expensive. Geographical Information Systems were used to analyse the spatial patterns of land covers identified, the sizes and shapes of spatial entities and the spatial distribution of land cover types in relation to slope and proximity to rivers. The likely ecological effects of land cover change were investigated by deriving habitat suitability maps using the habitat requirements of seven large herbivore species: buffalo, bushbuck, elephant, kudu, sable, waterbuck and zebra.

Miombo woodland and woodland with termitaria (patches of dense vegetation on termite mounds) were fragmented by cultivated, grazed/cleared and settled land and to a lesser extent by open miombo woodland by 1993. This was shown by total areas of land cover types, and patch sizes and shapes. The extent of fragmentation was greater in the settled area compared with the wildlife area and the whole study site, as most of the culivated, grazed/cleared and settled land was found there. These land cover types occurred mostly within 1 km of rivers and on flat land of between 0 and 4 degrees of slope. Miombo woodland and cleared termitaria woodland were found on higher slopes than the other land cover types, especially in the wildlife area which had higher proportions of land with

steeper slopes than the settled area. This is part of the reason why it is unsuitable for cultivation. Analysis of habitat suitability for key species showed habitat loss for buffalo, elephant, kudu and zebra and fragmentation for all species. Elephant would be least affected by fragmentation as they are habitat generalists, have large home ranges, can travel long distances without water and will enter settled areas. Bushbuck would be the most affected as they are secretive animals with small home ranges confined to areas with good ground cover and close to water points. The tsetse fly control hunting operations between the 1950's and 1970's depleted the area of wildlife populations which has since been exacerbated by poaching in the area. There are attempts to improve wildlife populations through the Communal Areas Management Programme for Indigenous Resources (CAMPFIRE) which is generating income for Kanyati residents, mainly from trophy hunting in the area.

This analysis of the pattern of land cover change quantified habitat fragmentation, which would not have been reflected by simply assessing total areas of particular land cover types or habitats. Estimates of total suitable habitat for each species in 1993, showed that the size of most fragments were inadequate to support resident populations of large mammals. There were nonetheless a few areas of suitable habitat, especially in the wildlife area which would support such wildlife populations. Finally, further research questions are identified, which would continue this initial study of land cover changes at this scale in the communal lands in Zimbabwe, and their effects on biodiversity.

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ACRONYMS USED

ARDA	Agricultural and Rural Development Authority
CAMPFIRE	Communal Areas Management Programme For Indigenous Resources
GIS	Geographical Information System
RDC	Rural District Council
VIDCO	Village Development Committee
WWF	World Wide Fund for Nature

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1. INTRODUCTION

Areas under cultivation and settlement are expanding globally with significant effects on existing land cover types and ecosystems (Turner II *et al.*, 1995). The World Bank estimated in 1989 that 80 to 90% of Africa's rangelands and 80% of cropped land in dryland areas may be affected by soil degradation, at least partially due to high population growth rates (Meltzer & Hastings, 1992). The rate of human population increase of 3.5% annually in southern Africa and subsequent increased pressure on land, has led to further extension of cultivation and settlement into marginal lands (Campbell *et al.*,1989). An extensive study of the clearing of land for subsistence agriculture in the Zambezi Valley in Zimbabwe showed an average rate of clearance of almost 5% per annum between 1951 and 1993, and 8% from 1981 - 1993 (Cumming & Lynam, 1997). One of the major causes of declining biodiversity from an area is loss and fragmentation of habitat as land cover types are converted. Loss of habitat is the most frequently cited factor in local and more permanent extinction of a species (Pimm *et al.*, 1995; Ehrlich and Ehrlich, 1992). This is a major concern in areas under communal tenure in Zimbabwe with community-based natural resource management programmes, based on sustainable wildlife utilisation.

Human activities are crucial in the dynamics of miombo woodland, which is typical of moist savanna ecosytems comprising broad-leaved, deciduous woody vegetation. In seven southern and central African countries, miombo ecosystems provide livelihoods for approximately 39 million people, which includes areas with the lowest *per capita* income and highest *per capita* population growth rates in the world (Desanker, *et al.*, 1997). Large areas of woodland in Zimbabwe have been converted to cultivated land and changed by harvesting for fuel wood, frequent burning and grazing (Desanker *et al.*, 1997; Du Toit *et al.*, 1994).

There is a need to document environmental trends as population growth and cultivated areas increase with subsequent decreases in natural vegetation (Cumming, 1993; Turner II *et al.*, 1995). A spatial approach analysing patterns of land cover change reveals more subtle processes of land transformaton. Little work has been done on the nature and extent of land cover change such as fragmentation of woodland over time, in relation to landuse in Zimbabwe at scales finer than a national scale. Meltzer and Hastings (1992) assessed the stability of grass and wooded patches in a fragmented landscape in Runde Communal lands in Zimbabwe. They measured the stability of these patches over the period 1968 – 1985 with increases in cattle populations, using fractal dimensions as complexity of shape measures. On average increasing cattle numbers resulted in disintegration and loss of grass and wooded patches over time, except for small grass patches which remained stable. This study did not incorporate the use of Geographical Information Systems (GIS), which enable the capture and analysis of large spatial data sets and facilitate area and perimeter measurements. A study on the rate of land converted to cultivation and settlement, on a broad scale in the Zambezi Valley over the past four decades, involved the assessment of cultivation and settlement areas from aerial photographs. Areas were measured at the resolution 500m x 500m.

Broad trends of land converted to cultivation and settlement were identified but did not include other land cover types or a detailed analysis of the spatial pattern.

This study describes a method and results of analysing the pattern of land cover change using aerial photographs and GIS in Kanyati Communal Land in Zimbabwe. Kanyati is one of the last areas along the Zambezi valley escarpment with reasonably well-preserved miombo woodland (Colquhoun, O'Connell & Partners, 1990). This is particularly evident in the contrasting state of the woodland on the western side of Sanyati in Matusadona National Park. The park has similar topography and vegetation but the mature woodland has been removed by elephants and fire (Cumming *et al.*, 1997). Kanyati, which has not been subjected to high elephant densities, is divided into a wildlife area and a settled area by a game fence erected in the early 1990's. This provides a unique opportunity to compare the patterns of land transformation with and without extensive human impact. Investigation of fragmentation of the miombo woodland in the area by human settlement and possible effects on the biodiversity of the area is of particular interest in the context of wildlife utilisation as a land use.

In Zimbabwe, 42% of the land comprises communal lands of which 74% fall mainly within Natural Regions IV and V which are considered to be unsuitable for dry land cropping due to low and erratic rainfall (Danley *et al.*, 1994; Cumming & Bond, 1991). Serious environmental problems are evident in some of the communal lands and resettlement areas such as severe erosion and overgrazing in some areas. Definitive proof of overstocking and decline in productivity of communal rangelands as a result, is lacking, which has been misinterpreted to mean that serious land degradation in the communal lands is not occurring (Scoones & Wilson, 1988). In many communal lands in the Zambezi Valley, dry-land cropping is a risky land use because of the extreme variability of the environment, the marginal nature of the land and the communal tenure (Cumming & Bond, 1991). Wildlife utilisation or multispecies animal production systems are increasingly being advocated as the most sustainable use of the semi-arid to arid communal lands (Cumming, 1993; Danley *et al.*, 1994). Community-based resource management programs such as CAMPFIRE (Communal Areas Management Program For Indigenous Resources) have successfully promoted sustainable wildlife utilisation in several communal lands in Zimbabwe. This aims to provide an opportunity for local communities to generate income from managing the natural resources within their area through for example, trophy hunting and ecotourism ventures. Assessment of the long-term sustainability of this type of resource management has been based on population surveys of wildlife populations. There has been no investigation of the possible impacts of this resource management strategy on the spatial distribution of the natural vegetation, which constitutes habitat for many of the key income-generating species. Kanyati Communal Lands were granted the authority to use and benefit from wildlife resources under CAMPFIRE in 1990 (the authority was given and is administered through the Nyaminyami Rural District Council). This study aims to inform CAMPFIRE policies and recommendations by providing a method for describing spatial patterns of habitat change as a basis for investigating likely impacts of settlement on biodiversity.

1.1 Problem statement

The spatial pattern of land cover change and habitat fragmentation over time, and the possible effects this may have on biodiversity in the communal lands in Zimbabwe, has previously not been examined. A methodology needed to be developed to investigate land cover change with time. Satellite imagery is only available from 1980 onwards in this country and is very expensive to obtain, especially as it was desirable to capture data on the scale of 1:25 000 (relatively high resolution). Blanket aerial photography is available in many parts of Zimbabwe extending back to the 1950's so allowing data to be captured over long time periods.

1.2 Objectives of research project

This study aimed to investigate patterns in land transformation in a Zimbabwean landscape from a spatial, geographic point of view (i.e. using a spatially explicit approach). Patterns of land cover change, especially the rate of miombo woodland fragmentation in Kanyati Communal Land were analysed over the period 1973 - 1993. The spatial distribution of the land cover types in relation to terrain and proximity to main rivers was ascertained. The likely impacts of the changes in land cover types for several key species were to be assessed, based on their habitat requirements.

1.3 Hypotheses

The following hypotheses were formed from a preliminary literature review of general trends of the expansion of settled areas in the communal lands in Zimbabwe, and reports on land use in the study site.

1. The natural vegetation/woodland was increasingly fragmented over the twenty year period, by encroachment of cultivated and settled land with time. This is in spite of the broken terrain and relative unsuitability of the land for dryland cropping.
2. The natural vegetation will be more fragmented by cultivation in the settled area compared with the wildlife area, and the area as a whole.
3. Cultivation and settlement occur in low-lying areas and the tops of flat ridges.
4. Habitat loss for large mammals will be greater in the settled area.

1.4 Research questions

1. What is the pattern, if any, of habitat fragmentation resulting from settlement and cultivation?
2. What was the nature of land cover change in terms of fragmentation and substitution over the period of 1973 to 1993?
3. How does a decrease in the geographical extent of analysis affect the measured rate of fragmentation of woodland in the areas that are settled and cultivated by 1993?

4. Is there a relationship between land cover types (especially cultivation and settlement) and terrain?
5. Is change in land cover type related to proximity to rivers?
6. What is the ecological significance of this fragmentation in terms of the spatial requirements of key species?

2. LITERATURE REVIEW

2.1 Land Cover Change/ Transformation

Land cover can be defined as "the biophysical state of the Earth's surface and immediate subsurface" (Turner II *et al.*, 1995). Land cover change or transformation includes the conversion and modification of land cover. For the purposes of this study the term land transformation shall mean "land cover change" as opposed to the usage of this term associated with socio-political development issues. In a study of land use change over 160 years in Illinois, Iverson (1988) found that the patches of land were increasingly controlled by human influences and relatively few by topographic and hydrological features. Although it is difficult to separate natural causes from anthropogenic causes of land transformation, the majority of rapid land cover change in Zimbabwe presently is caused by human activities, altering land covers for production and settlement. Land cover change is primarily driven by land use which is in turn is caused by " complex political, social and economic processes" (Turner II *et al.*, 1995).

The increasing rate of human-induced land transformation especially the pattern of habitat conversion is a primary concern in the conservation of biodiversity globally. Land cover change has resulted in significant losses in species numbers and varieties world-wide, which affects long-term ecological processes and genetic diversity (Turner II *et al.*, 1995). Habitat fragmentation and loss of habitat are typical causes of local extinction of species. For example habitat reduction is the most frequently cited factor causing extinction of birds - approximately 75% of threatened species (Pimm *et al.*, 1995). Koopowitz, Thornhill and Anderson (1994) used the rates of habitat conversion and the distribution of species as prime factors in a global model of extinction rates and prediction of numbers of species lost.

2.1.1 Spatial pattern of land cover types

The spatial arrangement of ecosystems, habitats and communities has ecological implications (Turner, 1990), but the extent to which physical causes or processes can be observed from analysis of spatial patterns is a contentious issue (Rex & Malanson, 1990). O'Neill, *et al.* (1988) found a strong link between spatial pattern and ecological processes within a landscape, for example, the spatial arrangement of disturbances affected the movement and dispersal of animals. Spatial patterning of resources constrains the movement of organisms on a landscape so that sparse resources may require an organism to operate on larger resource utilisation scales (travel further for food) (O'Neill *et al.*,1988). The study of pattern isolated from biological processes that generate it is not likely to advance ecosystem theory in itself but it will provide a basis for further questions (Rex & Malanson, 1990).

The principle that changing the spatial configuration of habitats can mitigate the risks of species extinction from habitat loss was proposed by Kareiva and Wennergren (1995) and contested by Fahrig (1997) and Trzcinski *et al.* (1999). In Fahrig's study the amount of breeding habitat had a much greater effect than fragmentation in a spatially explicit simulation model (i.e. model explicitly defines areas). If a breeding habitat occupied more than 20% of a landscape, survival was virtually ensured no matter how fragmented the habitat. The exact value of this threshold will depend on the habitat requirements and demographic potential of the organism and the absolute scale of the landscape.

A spatial approach to the problem of habitat loss allows the distinction between a quantitative process such as habitat loss from a qualitative one such as habitat fragmentation (Bascompte, 1996). The effect of habitat fragmentation on biodiversity is related to the geometry of the disturbance and to the nature of the land cover type replacing the original cover. This indicates that spatial pattern of land cover change and fragmentation of particular land cover types are crucial measurements to be made (Turner II *et al.*, 1995).

This study aimed to investigate patterns in land transformation in a Zimbabwean landscape from a spatial, geographic point of view (i.e. using a spatially explicit approach). There are several levels of analysis possible and in this study the focus was on the patch, land cover type and entire landscape.

2.1.2 Spatial configuration and composition of landscapes

Forman (1995) defines a landscape as 'a mosaic where a cluster of local ecosystems is repeated in similar form over a kilometre-wide area'. The configuration of a landscape is the spatial distribution of land cover types within its boundaries. Most landscapes are spatially heterogeneous as they have an uneven, non-random distribution of spatial elements. Heterogeneity is scale-dependent as landscape phenomena can be caused by processes operating at different scales varying from one meter squared to several kilometre squared (Pickett & Cadenasso, 1995). Landscapes are often described as a nested hierarchy with different elements having their own scales in space and time (Holling, 1992). Holling (1992) defined the dimensions of a boreal forest landscape as having dimensions of ten to hundreds of kilometres squared and a temporal scale of thousands of years. The spatial pattern of an area or landscape is often described as comprising patches, corridors and matrix. The matrix is the land cover type characterised by extensive cover, high connectivity or contiguity and may exert a dominant effect over the dynamics of other land cover types and ecosystems (Forman, 1995). A corridor is a conduit for organisms between patches of similar habitat, a barrier between patches of the habitat through which an organism passes and an area of habitat in its own right. A patch is a "relatively homogeneous non-linear area that differs from its surroundings" (Forman 1995). It is also defined as a group of contiguous, adjacent cells (diagonal cells are not included) of the same land cover in a digital (raster) image (Turner, 1990). Holling (1992) identified patches in boreal forest ecosystems as tens of metres squared and having a time scale of decades up to a century. Stands were defined as more than ten to hundreds of metres squared (less than one km^2) with the same time scale as patches. Forests were defined as 1 - 10km^2 with time scales of centuries. In this study the separate spatial elements within the landscape comprise mostly patches and stands, but with larger size classes too.

Forman (1995) defines five main origins/causes of patches: natural disturbance, remnant (small area remaining undisturbed), environmental (microheterogeneity of environment such as soil type variations), regenerated (regrowth on previously disturbed site) and human induced. The persistence of patches within a landscape over time is a function of their origin. For example, remnant patches may disappear or change more rapidly than environmental patches, which change slowly reflecting the stability of the substrate. There are ecological values of both large and small conservation areas documented in the 'SLOSS' debate in biogeography: whether a Single Large or Several Small (SLOSS) areas are optimal designs for conservation areas. Generally speaking large patches have greater benefits than small patches, but the latter provide supplemental benefits (Forman, 1995). Hansson and Angelstam (1991) state that the SLOSS debate is unsolvable because extinction risk is dependent on species-specific demographic and genetic conditions, and the degree of connectivity of patches. They conclude that small dispersed patches with important community components are just as significant as large expanses of homogenous habitats, but the debate continues. Most ecological emphasis on patch size concerns species, but Hobbs (1993) concludes that habitat fragmentation on ecosystem processes is just as great although little is known. The size of areas of indigenous vegetation or habitat and their connectivity are particularly significant ecologically. The table below outlines the benefits of different characteristics of habitat area and connectivity.

Table 1 Ecological effects of habitat size and patch connectivity

(adapted from Forman, 1995)

Habitat area	Large	Protects: • hydrology: lakes & aquifers • patch-interior species habitat • large-home-range species habitat • sources of species dispersing through the matrix • natural disturbance regime
Habitat area	Small	Significant in terms of: • habitat and stepping stones for species dispersal and recolonisation after local extinction of interior species • enhancing matrix heterogeneity therefore ameliorating negative effects of erosion and fetch • habitat for small-patch-restricted species and edge species
Connectivity	High	• enhances recolonisation after frequent local extinction events • enhances gene flow to guard against inbreeding depression in a patch • reduce fetch and erosion in the matrix
Connectivity	Low	• decreases the spread of pests, non-indigenous species and disturbances • decreases the "sink effect" on interior species which is an increase in mortality caused by use of unsuitable corridors

Another important consideration when assessing the viability of a patch to support wildlife is the nature of the surrounding land cover. If a suitable habitat patch is bordered by inhospitable land cover this would have a significant effect on the composition of animal communities inhabiting that patch. The type of vegetation adjacent to forest fragments was found to have a significant effect on their habitat quality and the composition and structure of bird communities within (Estades & Temple, 1999; Sisk *et al.*, 1997 and Hanowski *et al.*, 1996).

2.1.3 Land transformation processes

The fragmentation of natural habitats is an inevitable consequence of land transformation. Habitat fragmentation can be viewed as one of many spatial processes of land transformation, all of which are ecologically significant and therefore should be examined in conjunction with fragmentation. Forman (1995) identifies four other common spatial processes:

Perforation : process of gap creation in a habitat or land type, and which usually instigates further changes in that land cover

Dissection: subdivision of an area, such as the clearing of land for roads

Fragmentation: breaking up of habitat or land type into smaller portions

Shrinkage: decrease in patch or corridor size

Attrition: disappearance of patches and corridors, usually small ones.

These processes all have particular impacts on the spatial attributes of the landscape and therefore different effects on the ecology (see Table 2). Most of them result in habitat loss and isolation of patches and consequently the organisms within them. Isolation occurs when habitat patches and the species within them are surrounded by inhospitable or undesirable habitat, restricting movement away from the patch. Perforation, dissection and fragmentation may occur over an entire area or in small patches within this; whereas shrinkage and attrition are usually associated with individual patches or corridors. The number and density of patches increases in fragmentation and dissection of habitat, and decreases with attrition. Average patch size decreases in perforation, dissection, fragmentation and shrinkage and increases upon attrition as small patches are more likely to disappear. The ratio of interior to edge habitat of patches decreases in all five processes. Connectivity across the landscape in terms of corridors or matrix, usually decreases with dissection and fragmentation.

Perforation and dissection processes usually occur as the initial phases of landscape transformation, followed by fragmentation and shrinkage processes and finally attrition (Forman,1995). Attrition is regarded as leading towards complete habitat destruction and therefore increasing the probability of local extinction of the species surviving within this habitat (Hanssen & Angelstam, 1991).

The definition of habitat fragmentation above is preferable to the more general use of the term to describe all land transformation processes, or when it is taken to mean the combination of habitat loss and isolation. Fragmentation is rather a subset of the broader processes of land transformation, habitat loss and isolation.

Table 2 Summary table of spatial processes and their effects
(adapted from Forman, 1995) ↓ = decrease ↑ = increase '--'= no change

Spatial process	Asociation	Avg. patch size	Patch number & density	Inter-patch distance	Interior to edge ratio	Connectivity
Perforation	occurs over entire area or in small patches within this	↓	--	--	↓	-- or ↓
Dissection	occurs over entire area or in small patches within this	↓	↑	↑	↓	↓
Fragmentation	occurs over entire area or in small patches within this	↓	↑	↑	↓	↓
Shrinkage	individual patches or corridors	↓	--	↑	↓	↓
Attrition	individual patches or corridors	↑ or ↓*	↓	↑	↓	↓

* *increase or decrease in average patch size depends on whether large or small patches are preferentially removed*

2.2. Effect of spatial pattern and process of land cover change on species

Species numbers and diversity in terrestrial patches are in part controlled by patch area, habitat diversity, disturbance, patch interior area, age, matrix heterogeneity and isolation. Patches caused by disturbance are often characterised by rapid species turnover resulting in openings and gaps. Species evolved with disturbance regimes and all species may require, and are maintained by disturbance (Forman, 1995). *Minimum dynamic area* is the patch size required to avoid species elimination by a natural disturbance regime, and is a larger area than predicted by species-area curves. It allows for movement away from disturbance patches. The *minimum viable population* is the minimum number of individuals required to maintain a population over the long term, although the estimation of minimum viable population is controversial. Loss of genetic variation and demographic changes cause a decrease in numbers and possible extinction of small populations. Low genetic variation also causes inbreeding depression, outbreeding depression, swamping and a decrease in evolutionary flexibility to cope with habitat changes (Forman, 1995).

2.2.1. Patch size effects

The effect of the size of the habitat patch on a species depends on the spatial requirements of that particular species. Some may be restricted to relatively small patches (such as edge species) and others to large patches. Larger patches generally have more species than smaller patches, and area is more important in predicting species numbers within a patch than isolation, patch age and other variables (Forman, 1995). Some species thrive in the interior of habitat patches and others prefer the edges.

Bender *et al.*, (1998) investigated patch-size effects from 25 studies and concluded that population size of interior species decreased more with habitat fragmentation than from habitat loss only, with the opposite effect for edge species. In other words the population size decrease will be less than that predicted by pure habitat loss for edge species. This is due to interior species becoming more exposed to the deleterious effects of non-interior habitat with habitat fragmentation.

Patch size effects are more commonly observed for edge and interior species than for habitat generalists, although many studies use the total patch area as opposed to the portion inhabited by the species in question for density calculations. This results in an underestimation of patch size effect for edge species in large patches, and for interior species in small patches (Bender *et al.*, 1998). In landscapes with a higher proportion of habitat suitable for a species, configuration of the habitat is less important than a landscape, which has a lower proportion of this habitat. Negative effects of patch size and isolation on the original sets of species may not occur until the landscape consists of only 10-30% of the original habitat. These effects will also depend on the suitability of the surrounding habitats and the mobility of the organisms (Andrén, 1994).

In order to determine the best indicator of species richness of terrestrial mammals in forests, Bennett (1990) compared area and diversity of habitat, extent of disturbance to forest vegetation and time since isolation. The area of the forest was found to be the best indicator. The degree of connectivity between patches and populations was also found to be a critical component for the conservation of fauna in fragmented environments. Corridors can facilitate the spread of catastrophic disease epidemics and therefore be more of a threat than aid to conservation in some cases, as documented by Young (1993) with respect to natural die-offs of large mammal populations.

2.2.2. Connectivity

Connectivity is how connected or spatially continuous a spatial element such as a corridor or matrix is. The fewer gaps between land covers of the same type, the higher the connectivity. The spatial arrangement of habitats in a landscape determines connectivity through heterogeneity in habitat quality, and variations in patch shape, size and isolation (Keitt, Urban & Milne, 1997). Functional or behavioural connectivity refers to how connected an area is for a particular process, such as an animal moving through different types of landscape elements. A landscape may be structurally disconnected into sections or fragments while being behaviourally or functionally connected for a particular animal which is able to traverse small non-habitat areas (Forman, 1995). Matrix or dominant land cover type conditions are important in controlling connectivity in the landscape. These influence the dispersion and migration of most organisms, depending on whether the dominant land cover is inhospitable or provides habitat for them (Kohm & Franklin, 1997). In the case of most studies analysing spatial pattern and land cover change, the dominant land cover or matrix is agricultural or cleared land which can limit the movement and habitat of organisms within a landscape.

Species with spatially separated habitat patches are said to be significantly affected by landscape changes particularly habitat fragmentation, especially when they have a low dispersal rate (Verboom & van Apeldoorn, 1990). Merriam *et al.* (1989) stated that many animal populations in heterogeneous environments are structured spatially and functionally as demographic metapopulations. The term 'metapopulation' was first defined by Levin in 1969 and is said to comprise similar-sized, interconnected local populations that function as a unit in terms of movement frequencies, productivity and reproductive rates (Arnold *et al.*, 1993). Levin (1970) stated that the probability that a subpopulation will become extinct increases as patch size is reduced and with increased patch isolation (Verboom & van Apeldoorn, 1990). This is however contingent on dispersal capabilities and distances between patches as well as the presence and distribution of barriers and corridors. Heterogeneity created in agricultural landscapes may create barriers to movement where distances between patches exceed the maximum distance travelled by species in one movement (Arnold *et al.*, 1993).

2.2.3. Keystone or indicator species

Species cascade or ripple effects occur when local extinction of a singe species, or group of species, causes changes in the structure and function of a community (De Leo & Levin, 1997). Subsequent loss of other species from the community may then occur. Such species can be described as *keystone species* whose decimation can have widespread ecological effects. These are usually area sensitive species with low population densities (Burkey, 1989). Holling (1992) proposed an extended keystone hypothesis: "all ecosystems are controlled and organised by a small number of key plant, animal and abiotic processes that structure the landscape at different scales" (p.478). Knowledge of the spatial distribution of keystone/indicator species and other resources deciding community integrity is needed for conservation management. Hansson and Angelstam (1991) describe the ideal attributes of keystone species as being well adapted to one or more biotypes and persistent in the long-term in the area. Indicator species may not demonstrate the importance of natural mosaics or external influences equally well for whole communities, but are nonetheless useful for monitoring and managing fragmented biotypes (Hansson & Angelstam, 1991).

This study uses the habitat and home ranges of certain species to investigate effects of fragmentation of miombo woodland.

2.2.4. Resource Utilisation

Holling (1992) proposed that all animals 'measure' landscape elements with a spatial grain defined as a function of their size based on the relationship between home-range size and body mass. Furthermore the spatial extent of home ranges of mammals of the same body mass is determined by the productivity of the landscape and by their trophic status. The less productive the landscape and the further up the trophic chain, the larger the spatial extent of their foraging areas. Holling (1992) then stated that birds and mammals, and animals in the same trophic levels have a similar response to the geometric structure of resources available at different scales. The spatial grain and resource utilisation scale of humans is not contingent on body-mass but on technological innovations which can expand the impacts on the environment from regional to global scales (Holling, 1992).

2.2.5. Effects of fragmentation

Natural processes and human activities cause fragmentation, which may be a single event, sequential or continuous processes. Fragmentation occurs at different scales. Fine scale fragmentation is postulated to have particularly negative effects on small organisms, specialist species and ecosystem functions. The main descriptors of fragmentation are patch size, number, connectivity and isolation (Forman, 1995). Fragmentation at finer scales is considered to pose a greater risk to landscape connectivity than the same reduction of habitat at a coarser scale (With, 1997). Landscape fragmentation results in different effects depending on the size of animal involved and grain of fragmentation (Holling, 1992). Hobbs (1993) found that the effects of fragmentation and removal of native perennial vegetation on ecosystem processes were changes in the hydrological cycles, radiation balance and wind regime. These were a result of rapid clearance of native vegetation for crop/pasture systems, which were causing agricultural land degradation.

Fragmentation usually causes the following spatial effects:

- increases in patch density, inter-patch distance, boundary length, stepping stones and corridors;
- decreases in patch size, connectivity, interior-to-edge ratio, maximum size of core and total interior area;

- variable effects on patch shape and fractal dimensions depending on the pattern of fragmentation.

The impact of fragmentation on species:

- increases in habitat isolation, number of generalists, number of edge species, number of exotic species, nest predation and extinction rate;
- decreases in dispersal of interior specialists, large-home-range species (of initial habitat type) and interior species richness. Other species, which would be negatively affected by fragmentation, are species dependent on more than one type of habitat; for example, the habitat is segregated according to hibernatory and reproductive phases (Abensperg-Traun *et al.*, 1996; Andrén, 1994; Arnold *et al.*, 1993; Fahrig, 1997; Forman, 1995; Herkert, 1994; Hobbs, 1993; Langrand, 1995; Little & Crowe, 1998; Murcia, 1995; Verboom & Van Apeldoorn, 1990)

The consequences of habitat fragmentation and loss on species will be influenced by the *pattern* more than the *extent* of habitat changed (Bender *et al.*, 1998). For example if habitat fragmentation in an area results in the reduction and removal of large patches, its effects would be different to the equivalent reduction in habitat with removal of only small patches. Habitat loss may have a larger effect than fragmentation on extinction probability (Fahrig, 1997) but fragmentation effects are more insidious with respect to the threat to biodiversity. This is due to the subdivision and decrease in the area of habitat, increase in the potential for edge effects and changes in the surrounding matrix. These

may affect the connectivity and continuity of the landscapes and therefore threaten the survival of sensitive species (With, 1997).
Habitat fragmentation may or may not produce spatial differentiation in the dynamics of populations (With, 1997). With (1997) stated that habitat fragmentation does not affect metapopulation structure but may still have important implications for the spatial structure of populations. For example dispersal among patches affects colonisation rates, connectivity and whether sub-populations function as a metapopulation. Fragmentation is frequently associated with metapopulation dynamics and genetic inbreeding, as well as decreases in internal habitat heterogeneity and sizes of disturbance patches (Forman, 1995). Increased homogeneity of landscape may cause increased probability of energy flow decreases and decreased resistance to disturbance (Holling, 1992). Communities that developed in relatively uniform and temporally constant environments may be more vulnerable to habitat fragmentation. For example, boreal communities may be more resilient to fragmentation than tropical species, but interior species are still at great risk.

Species that survive fragmentation are characterised by high dispersal and reproductive rates and generalised habitat selection permitting large-scale movements. Seasonally migrating species are at a lower risk than resident species (Hansson & Angelstam, 1991).

In a study of the effects of forest fragmentation on bird species in Madagascar, Langrand (1995) found that the number of bird species was positively correlated with the size of the forest fragments. Herkert (1994) found that both area and vegetation structure significantly influence grassland bird species distribution patterns in habitat fragments. Generally, insectivorous bird species seems to be more patch-size dependent than seed-eaters or omnivores, as are long-distance migrants compared with short-distance migrants/residents (Forman, 1995). Many migratory species are considered to be more area sensitive than resident species, but are more vulnerable to habitat loss than fragmentation, whereas resident species may suffer more negative patch-size effects from fragmentation. Bender *et al.*, (1998) found that mammals tended to have a stronger correlation between patch size and population density than birds although these differences were not significant as also found by Andrén (1994), nor were their responses to habitat fragmentation significantly different. There also seemed to be no significant difference between herbivores and carnivores for either interior or generalist species, although the negative effect sizes were slightly higher for herbivores. Vertebrates with large home ranges and/or small populations and those with large body weight are said to be susceptible to the negative effects of fragmentation and habitat loss. High reproductive and dispersal rates and generalised habitat selection in species are generally thought to ameliorate fragmentation effects (Bennett, 1990).

Fragmentation in its various forms has important ecological consequences and that a first step in the study of such consequences on species is a clear description of the pattern of land transformation. It is the description of these patterns and trends rather than the ecological impacts on particular species that form the focus of this thesis.

2.3 Issues of Scale

Different patterns emanate at different scales of investigation of ecological systems. Factors influencing spatial pattern may behave differently in a hierarchical manner and across varying spatial and temporal scales (Iverson, 1988). Holling (1992) identified three classes of processes (plant, animal and abiotic) which structure ecosystems over three different ranges of scale. At fine *microscales* of centimetres to tens of metres in space and days to decades in time, vegetative processes that induce plant growth, form and soil structure dominate spatial patterns. At a *mesoscale* of hundreds of metres to hundreds of kilometres and years to decades, contagious disturbance processes dominate pattern formation such as fire and disease. Human activities and large herbivore grazing may further change the spatial patterns at mesoscales, as can large predators and animal disease, which have indirect effects. At macroscales of hundreds to thousands of kilometres and centuries to millenia, slow geomorphological processes 'dominate the formation of a topographic and edaphic structure' (Holling, 1992). Wiens (1989) also stated that at broad scales (macroscales) physical processes might influence the spatial pattern of land cover more than biological effects on terrestrial ecosystems. At finer scales (microscale) the relationship between climate and vegetation may be overridden by the effects of competition and other biological processes (Wiens, 1989). Intermediate or mesoscale processes have a spatially contagious character where episode at the scale of a patch may have large-scale consequences. The spatial dynamics at this scale and the distribution of vegetation is dominated by animals, water, wind, fire and people (Holling, 1992). Human activities have the most effect on transforming land cover at the mesoscale. This study investigates spatial patterns at a mesoscale level of hundreds of metres to hundreds of kilometres over two decades.

Turner *et al.* (1989) defines scale as the spatial or temporal dimension of an object or process, characterised by both *grain* and *extent*. Absolute scale is the actual distance, direction, shape and geometry. Relative scale is the transformation of absolute scale to a scale that describes the relative distance, direction, or geometry based on some functional relationship, for example, the relative distance between two locations based on the effort required by an organism to move between them. Grain or resolution is the precision of measurement, for example, the resolution of an aerial photograph depends on the physical grain and contrast present, but also on the ability of the observer to distinguish spatial elements (Turner *et al.*, 1989). Extent is the areal coverage, size of study area, or the duration of time under consideration. The resolution and scale of the data will follow that of the smallest scale of data in a composite map (Unwin, 1996). Wiens (1989) describes extent and grain as comparable to the overall size of a sieve and its mesh size respectively.

Meentemeyer (1989) defines the determinants and constraints of selecting an appropriate spatial scale, some of which are: size and speed of spatial phenomenon being measured, scale of available maps, data handling thresholds (time, technology and money) and paradigm or discipline biases (such as landscape ecology). Spatial scale can influence results and measurements made at different scales will differ according to how scale is defined. These must therefore always be explicitly stated. The ability to predict how ecological variables change with scale affects extrapolation of information to larger scales, and comparison of data measured in different regions. Generalisation across spatial scales can result in erroneously influencing inferences, for example, relationships implied from higher levels of aggregation to a lower level (Meentemeyer, 1989). In a review of the effects of habitat loss and population decline in relation to patch size effects, Bender *et al.*, (1998) found no evidence that the absolute scale of the study or the range in patch sizes was related to the outcome of the study. He concluded that these studies were generally conducted at spatial scales significant to the organism studied. The scale of a study should ideally equate the perception of the organism with the attribute under investigation such as habitat. As this is often unknown units of scale are often 'selected arbitrarily based on observations of the behaviour of the animals' (Ben-Shahar & Skinner, 1988).

2.4. Measures of spatial pattern

Several indices measuring spatial pattern have been developed, most of which have been applied to landscapes in the United States. Spatial pattern indices describe the mosaic of a landscape of one area or at one moment in time, and give information on the configuration of a landscape, for example, the proportion of each land cover type and other information such as patch shape. McGarigal and Marks (1995) emphasise that the choice and interpretation of landscape metrics must be appraised in view of their ecological meaning, which is contingent on the definition of the landscape and selection of matrix and patch land cover types. Hulshoff (1995) stated that it is unclear whether they are useful for analysis of fine-grained landscapes (although it is recognised that this is a relative term). Andrén's (1994) critique of the landscape ecology models describing changing landscape patterns, points out that few attempts have been made to compare data on abundance and distribution of organisms in landscapes with different patterns and proportions of habitat. The indices are nonetheless useful in describing and analysing the pattern of land transformation in an area, especially in Zimbabwe where settled areas have increased rapidly in the communal areas over the last two decades.

The following measures of particular interest are described below and have been used in many other studies analysing spatial patterns and trends.

2.4.1. Patch size

Area and perimeter measurements are needed in the calculation of many of the indices. The smaller the patch the greater the influence external factors are likely to have. Smaller remnant ecosystems could primarily be driven by external factors rather than internal forces, which are referred to as edge effects. Larger areas have a bigger core area unaffected by environmental and biotic changes. The optimal actual size of a patch is species-specific (Saunders, Hobbs & Margules, 1991).

2.4.2. Proportion of land cover types in a landscape

This is a useful indicator of how land cover types change with time in an area and is also needed in the calculation of indices.

2.4.3. Patch configuration/shape

Forman & Godron (1986) suggested that patch shape influenced species dispersal, foraging efficiency and maintenance of habitat diversity. Patch shape is determined by variation in its margin or border. Compact shapes may have resulted from diverse processes over a long period whereas unidirectional processes (such as wind or water erosion) often produce elongated shapes. Human-created shapes are generally considered to be more geometric than those formed from natural processes. This is significant when investigating how patch shapes may change with human modification of land cover. The following measures of patch shape have been used:

a. Fractal dimension;

b. Hulshoff's shape indices; and these are described below.

2.4.3.a The fractal dimension

The underlying theory of fractals as defined by Mandelbrot (1982 *in* Burrough, 1986) is that for most naturally occurring phenomena, the amount of resolvable detail is a function of scale. An increase in map scale does not result in an absolute increase in precision but only reveals variations that had hitherto passed unnoticed (Burrough, 1986). Fractals have the characteristic of being self-similar which is the way in which variations at one scale are repeated at another. The idea of self-similarity of fractals means that if geographical objects such as mountains or rivers are true fractals, their variations should be scalable. Burrough (1986) asserts that the generalised fractal does not require self-similarity but an increase in variance with a decrease in scale. In a hierarchical sense a patch of land is composed of a cluster of smaller patches each of which is in turn composed of a cluster of still smaller patches. Meltzer and Hastings (1992) used a fractal exponent to determine the relative long-term stability of patches. Another related fractal dimension is the "space-filling property" calculated for the curvilinearity of a boundary. A straight line has a dimension of 1 and the fractal dimension increases progressively as a line becomes increasingly convoluted. Based on this a fractal dimension using a perimeter-area ratio, to quantitatively describe shape and texture is often used in studies of spatial pattern of land covers. This is estimated by doubling the slope of the regression line between log (area) and log (perimeter) such that:

$$D=2 * [\log (\text{perimeter})/\log (\text{area})] \quad \textit{or} \quad \text{Perimeter} = \text{Area}^{D/2}$$

(Berry, 1995, Iversen, 1988; Cullinan & Thomas, 1992, O'Neill *et al.*, 1988)

Turner (1990) measured the perimeter at a scale of length divided by four to account for the bias in perimeter in raster images (see also McGarigal & Marks, 1995; Pastor & Broschart, 1990). This would not be necessary if length and area measurements were computed in vector format of coverages. An increase in fractal dimensions can indicate an increase in fragmentation, as there is more edge for a given area with an increasingly complex boundary (Turner, 1990; Berry, 1993). O'Neill *et al.*(1988) found that estimates of D from aerial photographs generally captured the gross features of landscape pattern, although they were inconsistent when based on ground measurements (this is probably due to the different scales of measurement). Cullinan and Thomas (1992) advised that further research was needed on the estimation and interpretation of the fractal dimension and its relationship to landscape research. Rex and Malansen (1990) studied the fractal geometry of riparian forest patches as a useful descriptive index while recognising that such an analysis may not necessarily lead to an understanding of causal processes of patterns in itself. Studies by Iversen (1988), Krummel *et al.* (1987) and Turner (1990) showed that the fractal dimension was lower in disturbed patches relative to natural features and that smaller patches tended to have lower fractals. More complex shaped landscape components would have a higher fractal dimension. Iversen (1988) found little variation in the fractal dimension across different type of forest patches, and generally lower fractal dimensions in forests and wetlands/water bodies in Illinois than those recorded by Mandelbrot in 1977 (*in* Iversen, 1988). Mandelbrot found that land cover types controlled by topographic and hydrological patterns as opposed to human influences had fractal dimensions greater than 1.5. The lower fractal dimensions of the forest patches in Iverson's study may have been due to the fact that the forest perimeters were often straight lines adjacent to agricultural land i.e. no 'natural' boundaries.

Gustafson and Parker (1992) generated random landscapes using percolation theory and studied various spatial measures. The fractal dimension increased as the proportion of a land cover type increased with a slight decline, which was presumed to be due to changes in the patch area/perimeter relationships associated with the formation of a percolating cluster. The coalescence of several smaller patches caused a decrease in the fractal dimension when the proportion of a cover type was > 0.85. This may have been due to a reduction in patch irregularity as gaps were filled, as the area became more homogenous. This would mean that as the proportion of a land cover type in a landscape decreases so would the fractal dimension of the patches.

2.4.3b Hulshoff's shape indices

Hulshoff (1995) used two shape indices:

$$S1 = \frac{1}{N_i} * \sum \frac{Perimeter_i}{Area_i} \quad \text{(calculated per land cover type)}$$

where N_i = number of patches of category i

This measures the mean perimeter:area ratio of a land cover type, where a relatively high value represents many patches with small interiors.

$$S2 = \frac{1}{N_i} * \sum \frac{Perimeter_i}{4\sqrt{Area_i}} \quad \text{(calculated per land cover type)}$$

S2 is based on the fact that an isodiametric patch (circular or square) contains the most patch interior and calculates the deviation of a patch from an isodiametric patch with the same area. S2 is an average of this deviation for all the patches of a legend type. If a landscape comprises mostly isodiametric patches S2 will be small approaching one. The more S2 deviates from one the more the patches deviate from an isodiametric shape. S2 is comparable to the fractal dimension used by O'Neill *et al.* (1988) and Turner (1990) where it is a measure of the complexity of patch perimeter as compared to a perfect square or circle (Iverson, 1988). The above algorithm was adjusted for raster data but one for vector data is as follows (Forman & Godron, 1986):

$$S = \frac{Perimeter}{2\sqrt{Area\,\Pi}}$$

As patch shape becomes more complex and area larger, S1 decreases and S2 increases. When the complexity of the perimeter decreases and the area decreases slightly S1 remains stable and S2 decreases. When patch size remains stable and patch shape develops from complex to more square, both S1 and S2 decrease. Therefore S1 and S2 may have different ecological meaning as the changes in S1 indicate changes in the patch interior whereas S2 indicates changes in the complexity of the perimeter. Most patches of semi-natural land use types in the Netherlands are relict and fixed by their human-modified neighbour patches. Iverson (1988) stated that a complex 'natural' boundary does not exist where human activity has created part of or the whole boundary.

2.4.4. Proximity analyses

Proximity analyses give some indication of the spatial distribution of land cover types within a landscape. Associations with other land cover types, rivers and topography can be investigated. Berry (1993) recommends generating proximity surfaces using buffers indicating distance from each map location to its nearest neighbour. Large gaps would be reflected by large proximity values.

There are numerous other indices in the literature such as Shannon's diversity index, dominance, and evenness index calculated for entire landscapes, which are only meaningful if the spatial pattern of several landscapes are compared (Hulshoff, 1995; McGarigal & Marks, 1995; Medley *et al.*, 1995; Ritters, *et al.*, 1995; Turner, 1990). There are also many other different patch configuration and shape indices (De Pietri, 1995; Eastman, 1995; Gustafson & Parker, 1992; McGarigal & Marks, 1995; Ritters *et al.*, 1995; Turner, 1990). Contagion, dispersion, electivity and other proximity indices were considered (Gustafson & Parker,1992; Pastor and Broschart, 1990; Ritters *et al.*, 1995; Turner, 1990) but automated nearest-neighbour calculations were limited by available GIS software.

The spatial measures used in analyses were chosen for their applicability and meaning in the context and limitations of this study.

2.5 Habitat preferences for certain species

Habitat is defined by Fabricus and Mentis (1990) as ' the area containing the biotic and abiotic environmental components which enable the survival of a population of that organism'. Johnson (1990) defines four hierarchical orders of the spatial requirements of species: geographical range, home range, utilisation/avoidance of habitat components, and actual food plants preferred. Water and shelter would be additional important components to consider.

In order to create habitat suitability maps the habitat and spatial requirements of the species should be known. It is difficult to ascertain this as the spatial distribution of mammalian herbivores are based on the spatial and temporal availability and quality of food, cover and water (Ben-Shahar, 1995; Dekker *et al.*, 1996; Swanepoel, 1989). Seasonality is an important influence on the distribution and movement of ungulates. In the warm, dry season ungulates are widely separated in their use of plant communities with the opposite effect in the wet season (Afolayan & Ajayi, 1980; Dekker *et al.*, 1996). Water has a great influence of abundance and distribution in semi-arid savannas so that habitat suitability maps would show different spatial patterns in the wet and the dry seasons. There is a strong association between selection of habitat for specific landscape types and features. These features represent the general dimensions of habitats and include topography (measures of broken landscape and occurrence of boulders), vegetation composition and structure, and soil types (Ben-Shahar, 1995;

Ferrar & Walker, 1974). Home range sizes and movements within these tend to be highly flexible and adapted to a range of environmental conditions (Swanepoel, 1989).

In this study the habitat and spatial requirements of seven herbivore mammals species were obtained through a literature review of their habitat preferences and home ranges. These seven species were chosen for their presence in the study site area, with habitat requirements, which were compatible with the study site and for their potential to generate income in CAMPFIRE wildlife ventures.

2.5.1. Buffalo (*Syncerus caffer*)

Buffalo are grazers and need a plentiful supply of grass, shade and water, found within a 20 km 'foraging' radius of water but usually 5 - 10km (Beekman & Prins, 1989; Skinner & Smithers, 1990; Swanepoel, 1989). Taylor (1985) found that shade was not a limiting factor in the distribution of buffalo in Matusadona National Park in Zimbabwe[1], although they did still seek shade during the hottest time of the day. Suitable grasses are found in a variety of woodland types including mopane, *Baikiaea*, *Acacia*, and *Brachystegia* and in open vleis associated with these. They do not frequent open areas of grassland as they need shade, unless in transit or late/early in the day. The grass species *Panicum repens* was found to be the best available habitat in Matusadona, with the next preferred being escarpment base woodland savanna ecotone (Taylor, 1985). Swanepoel (1989) found that

[1] Matusadona is adjacent to the study area and comprises areas with similar topography and vegetation.

buffalo used Zambezi riverine vegetation, adjacent Mopane woodlands and Jesse thickets in the hot, dry season. Mopane woodlands were used initially in hot, wet season, after which herds moved into open woodland areas. In the cool, dry season riverine thickets and either tributary or Zambezi riverine areas were used. There was a change 1986/87 as riverine thicket, open Jesse and open woodland areas and miombo woodlands used in the hot wet and dry seasons (Swanepoel, 1989). Buffalo have been observed eating the nutrient-rich soil in termitaria that have been excavated by elephant and using them for shade (Ruggiero & Fay, 1994).

Sinclair (1977) reported a strong correlation between density and annual rainfall (equating to primary production). For areas with annual rainfall of 700 mm per annum, a density of 4 km^{-2} was expected, but lower densities have been found in other studies. Swanepoel (1989) found densities in Mana Pools National Park of 0.5 - 1.4 km^{-2}. Taylor (1985) recorded densities for bachelor herds of 0.5 - 3 km^{-2} in Matusadona National Park and Conybeare (1980) found an average density of 2.8 km^{-2} at Sengwa Wildlife Research Area, which is relatively close to Kanyati Communal lands. The overall density in protected areas in the Sebungwe, Zimbabwe in 1993 was 3.07 km^{-2} (Cumming, Taylor & Mackie, 1997). Breeding herds have a home range of between 60 and 70 km^2 although some studies have shown much higher values of 286 km^2 (Conybeare, 1980) and 430 - 637km^2 (Swanepoel, 1989) probably due to differences in food availability (Skinner & Smithers, 1990). Conybeare (1980) found that home ranges were larger in the wet season than in the dry season, and that the overlap between them was larger in the wet season.

In the same study the average distance moved by a herd of buffalo per day in the dry season was estimated at 6.1km.

2.5.2. Bushbuck (*Tragelaphus scriptus*)

Bushbuck are browsers and selective feeders, although able to modify feeding habits for survival in adverse conditions (Skinner & Smithers, 1990). Shrubs and herbs comprise the majority of their diet (Okiria, 1980). They prefer vegetation fringing watercourses, with correspondence analysis showing association with areas 200 - 1000m from water (Ben-Shar & Skinner, 1988; Du Toit & Owen-Smith, 1989; Okiria, 1980; Jacobsen, 1974; Skinner & Smithers,1990). They have a preference for *Acacia tortilis-Grewia flavescens* wood- and shrubland (Jacobsen, 1974; Ferrar & Walker, 1974; Skinner & Smithers, 1990). Their feeding activity is limited to a small area, preferably wooded, near water and along gullies and most intensive at night (Okiria, 1980; Skinner & Smithers, 1990). Anthills or termitaria are important habitat components used for shelter by Ferrar & Walker (1974). They have also been observed eating the nutrient-rich soil in termitaria that have been excavated by elephant (Ruggiero & Fay, 1994).

The density of bushbuck in Sengwa Research Area in the Zambezi Valley, Zimbabwe, was found to be 66 animals per km^2, with home ranges of $0.004km^2$ which may increase to $0.06km^2$ in dry seasons (Jacobsen, 1974; Skinner & Smithers, 1990).

2.5.3. Elephant (*Loxodonta africana*)

The elephant is a large, generalist herbivore occurring in a wide variety of habitats. A supply of and shade are essential habitat requirements, and food in the form of grasses and browse plants (Skinner & Smithers, 1990). The ratio between food types varies with availibility and season with more grass being eaten after a good rainfall season. They can be very destructive while feeding, uprooting trees and breaking branches to eat young foliage. Elephant browsing impacts savanna woodlands to such an extent as to change them to grasslands and shrublands (Lewis, 1991; Cumming *et al.*, 1997). Cumming *et al.* (1997) estimated that this would occur when elephant densities exceed approximately 0.5 per km^{-2} for more than a decade. Elephants in moist savannas are often observed excavating termite mounds, or termitaria. They eat the well-developed vegetation on termitaria, as well as the soil as it is high in certain minerals (Ruggiero & Fay, 1994). Elephant and termitaria may be keystone species in areas of low mineral nutrient availability, as they play an important role in nutrient cycling (Ruggiero & Fay, 1994).

Their home ranges vary in size between various habitats depending on availability of food and water. In the Zambezi Valley sizes of 94 to 263 km^2 were reported (Skinner & Smithers, 1990). In nature reserves adjacent to Kruger National Park, South Africa, female home ranges varied from 115 - 465 km^2 and males 157 - 342 km^2 (De Villiers & Kok, 1997). In northern Kenya home range sizes varied from 102 to 5527 km^2 for a single population (Thouless, 1996).

2.5.4. Kudu (*Tragelaphus strepsiceros*)

Kudu are browsers which inhabit savanna woodland and scrub, preferably tall, closed woodland providing protection and food (Dekker *et al.*, 1996; Ferrar & Walker, 1974; Skinner & Smithers, 1990; Underwood, 1978). Woody browse is their most important and preferred food resource, and they eat a great variety of browse plants (Ben-Shahar & Skinner, 1988; Skinner & Smithers, 1990). Preferred species are mainly from the families Tiliaceae (*Grewia flavescens*), Mimosaceae (*Dichrostachys cinerea*) and to a lesser extent Combretaceae (*Combretum molle*) (Ben-Shahar & Skinner, 1988). Cumming (D.Cumming, 1999, personal communication) found (in the 1970's) that in the Sengwa Wildlife Research Area of Zimbabwe the preferred habitat was *Combretum/Commiphora* habitats on escarpments and *Acacia* riparian communities on alluvial soils in Sengwa, Zimbabwe. *Baikaiea* woodland and *Combretum* thickets also ranked higher than miombo woodland. Males favour riparian woodland and thickets along drainage lines whereas female herds utilize a variety of habitats (Skinner & Smithers, 1990). Kudu are described as being "best suited to areas of bushveld offering a mixture of *Acacias*, broadleaf deciduous trees and evergreens, especially if forbs are also abundant" (Owen-Smith, 1985, p.9). Areas with extremely small-leafed *Acacias* or tannin-rich trees and shrubs typical of sandveld are not particularly suitable habitat for kudu, unless pockets of other vegetation can be found (such as rocky hillslopes). Anthills or termitaria were found to be important feeding habitat by Ferrar & Walker (1974).

Kudu have a preference for high soil nutrient areas which shows selection for habitats where vegetation is also high in food value (Underwood, 1978). They are associated with steeper slopes (3-9 degrees) and higher degrees of rockiness (40 to 60%) (Ben-Shahar & Skinner, 1988; Skinner & Smithers, 1990, Underwood, 1978).

The density of kudu in Nylsvley Nature Reserve (with similar densities in Kruger National Park) was 0.08 animals per km^2 per annum (Owen-Smith & Cooper, 1985). Kudu densities in Kruger National Park varied between 2 and 3 per km^2. Lower densities in lower rainfall years due to sensitivity of calf survival to rainfall fluctuations (Owen-Smith, 1985). Kudu females and their offspring form close social units with about 4 – 10 individuals and share a common home range. These units may subdivide further during food shortages in the late dry season. The home ranges of neighbouring social units overlap, and home range sizes vary depending on food density from about 1 – 10 km^2 (Owen-Smith & Cooper, 1985), to 3-25 km^2 in Kruger (Skinner & Smithers, 1990). Males form less cohesive groups and range over a wider area than the female groups, and join the female groups only during the breeding season (Owen-Smith and Cooper, 1985). Cumming (D. Cumming, 1999, personal communication) found that the average range size of four adult female kudu in separate herds was 9.7 km^2 while home ranges for two adult males was 27 and 32 km^2.

2.5.5. Sable (*Hippotragus niger*)

Sable are primarily grazers but sometimes browsers, especially towards the end of the dry season. They are found in savanna woodland and are dependent on cover and availability of water, with a preference for open woodland with adjacent vleis or grassland (Skinner & Smithers, 1990). They have a preference for higher canopy cover and avoid areas with high tree density with the preference overriding the avoidance (Ben-Shahar & Skinner, 1988; Skinner & Smithers, 1990). Sable avoid areas where grass is short from over-utilisation or other causes (Skinner & Smithers, 1990). They are found in close proximity to water sources (approximately 3 km from it), and have a preference for steeper slopes (3-9 degrees) and rockiness (40 to 60%) (Ferrar & Walker, 1974, Ben-Shahar & Skinner, 1988).

Home ranges of nursery herds (adult females and juveniles, usually comprising 20 animals), were found to be 0.2 - 0.4 km^2 in Kruger National Park, South Africa and 0.24 - 0.28 km^2 in Zimbabwe. Home ranges of territorial bulls are generally 0.025 - 0.04 km^2 (Skinner & Smithers, 1990).

2.5.6. Waterbuck (*Kobus ellipsiprymnus ellipsiprymnus*)

Waterbuck are predominantly grazers and roughage feeders. They have a significant preference for close proximity to water sources, because of unusually high water requirements and good quality grasses near water. Habitat may be open areas within reed beds or in woodland along the Zambezi river (Skinner & Smithers, 1990). They were found to have a negative association with low pH levels in soils (acidic), slope and areas of high basal cover of *Digitaria eriantha* and *Enneapogon pretoriensis,*. They have a preference for higher canopy cover with tree density of 801-1300 trees/ha (Ben-Shahar & Skinner, 1988).

Territories or home ranges in South Africa ranged from 0.66 - 2.8 km^2 (Skinner & Smithers, 1990). Mean territory size at Lake Chivero National Park[2] was found to be 0.895 km^2 with an overall density of 4.8 animals km^{-2} , which varied according to food quality, quantity and distribution (Tomlinson, 1981).

2.5.7. Burchell's zebra (*Equus burchelli*)

Zebra are predominantly non-selective, roughage grazers although they will occasionally browse (Beekman & Prins, 1989). They are often described as savanna plains species, with a preference for open areas of woodland, scrub and grassland where water is

[2] Lake Chivero National Park has as predominance of rocky outcrops in the west, evenly spaced termitaria in the east, different types of woodlands, grasslands and shoreline vegetation (Tomlinson, 1981).

available (Ferrar & Walker, 1974; Skinner & Smithers, 1990). They are usually found within 10 - 12km of water. They are associated with steeper slopes (3-9 degrees) and higher degrees of rockiness (40 to 60%) (Ben-Shahar & Skinner, 1988).

Zebra are non-territorial but sub-populations occupy overlapping home ranges of varying size: 111 - 262 km^2, with no correlation between group size and home range size. Smaller home ranges are associated with a good water supply and well grassed areas in comparison to larger ones with dense woodland and tall, unpalatable grasses (Skinner & Smithers, 1990).

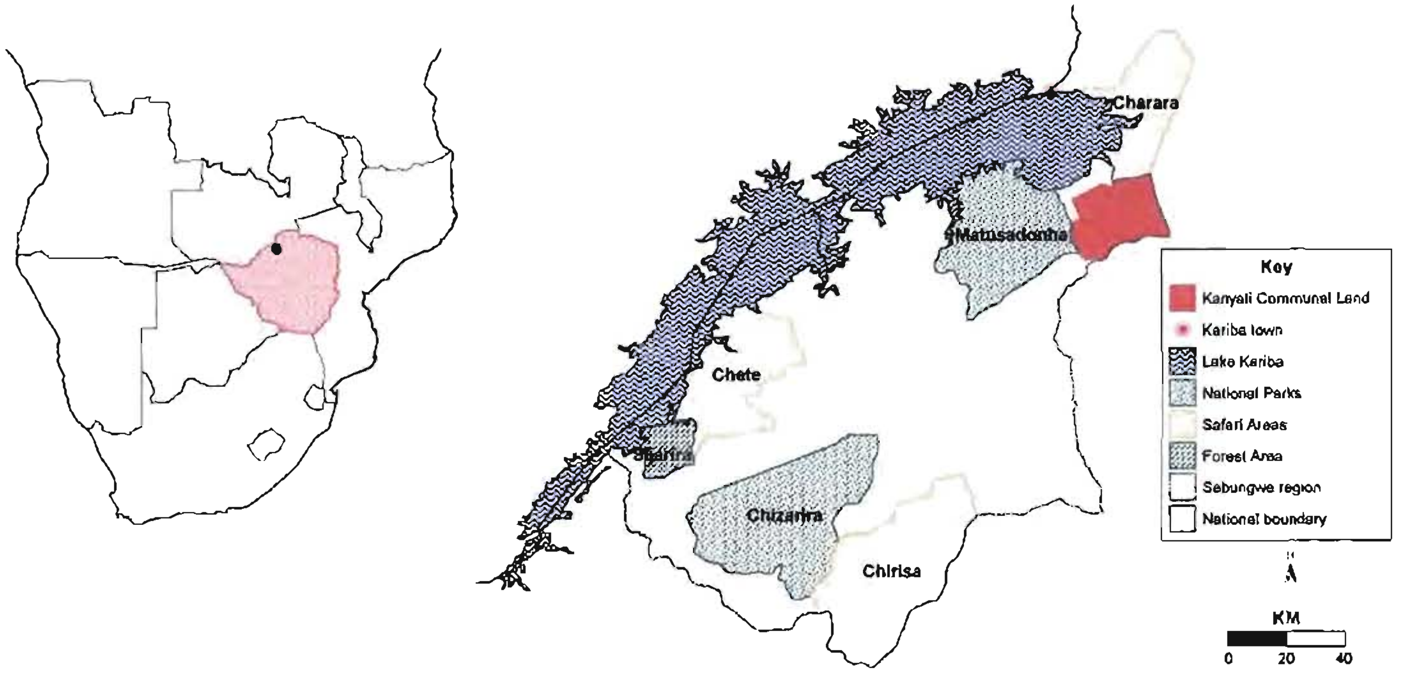
3. STUDY SITE DESCRIPTION

Kanyati Communal Land is situated in the Zambezi Valley in Zimbabwe, between Matusadona National Park in the west, Hurungwe Communal Land to the east and Charara Safari Area to the north-east. It is divided into two major land uses, a wildlife and a settled area, by a game fence erected in the early 1990's. Figure 1 shows the general location of Kanyati in Zimbabwe and details such as the administrative boundaries, game fence and main rivers.

3.1. Topography

There are two basic land forms in Kanyati. North of Gatche-Gatche river and west of Urange and Kaiwa rivers (wildlife area) the land is rough and broken, with rocky outcrops, forming the Zambezi Valley escarpment. Altitudes vary from 500m at Sanyati Gorge and increase to more than 1000m on the escarpment. The second land form is south of Gatche-Gatche and east of Urange and Kaiwa rivers (settled area)which is generally undulating, hilly with long slopes but interspersed with patches of broken country and has arable and grazing potential. Altitudes vary from 700-950m (ARDA, 1987; Anderson *et al.*, 1993).

Figure 2 shows a digital elevation model and slope map to show topography in Kanyati. Note the difference between the wildlife area west of the game fence, and the settled area which is east of the game fence.



Location of Kanyati Communal Land in Southern Africa and Zimbabwe

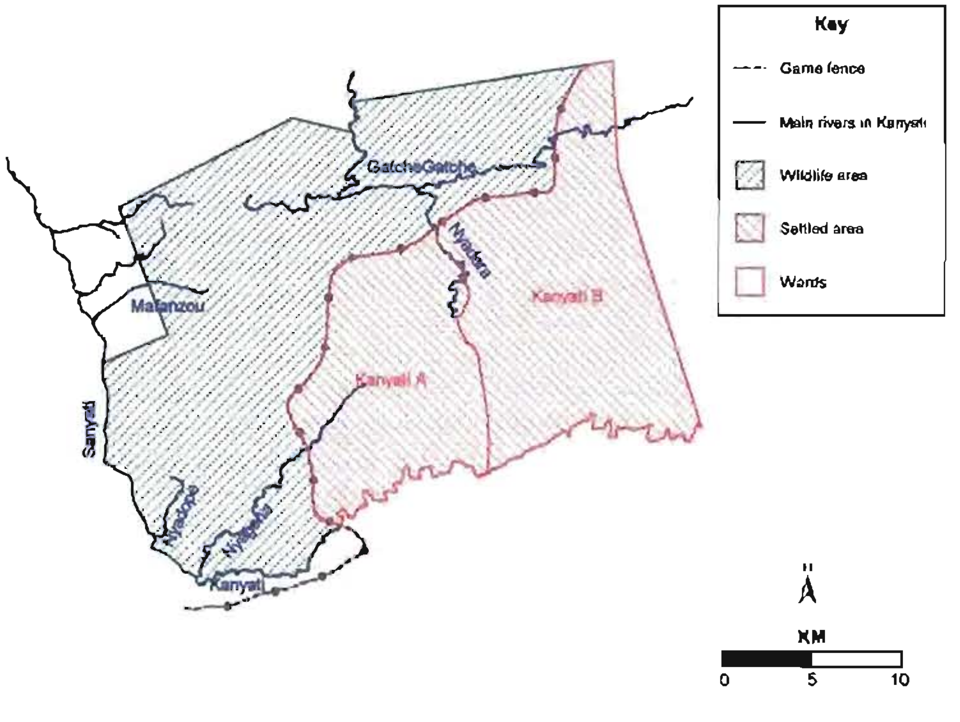
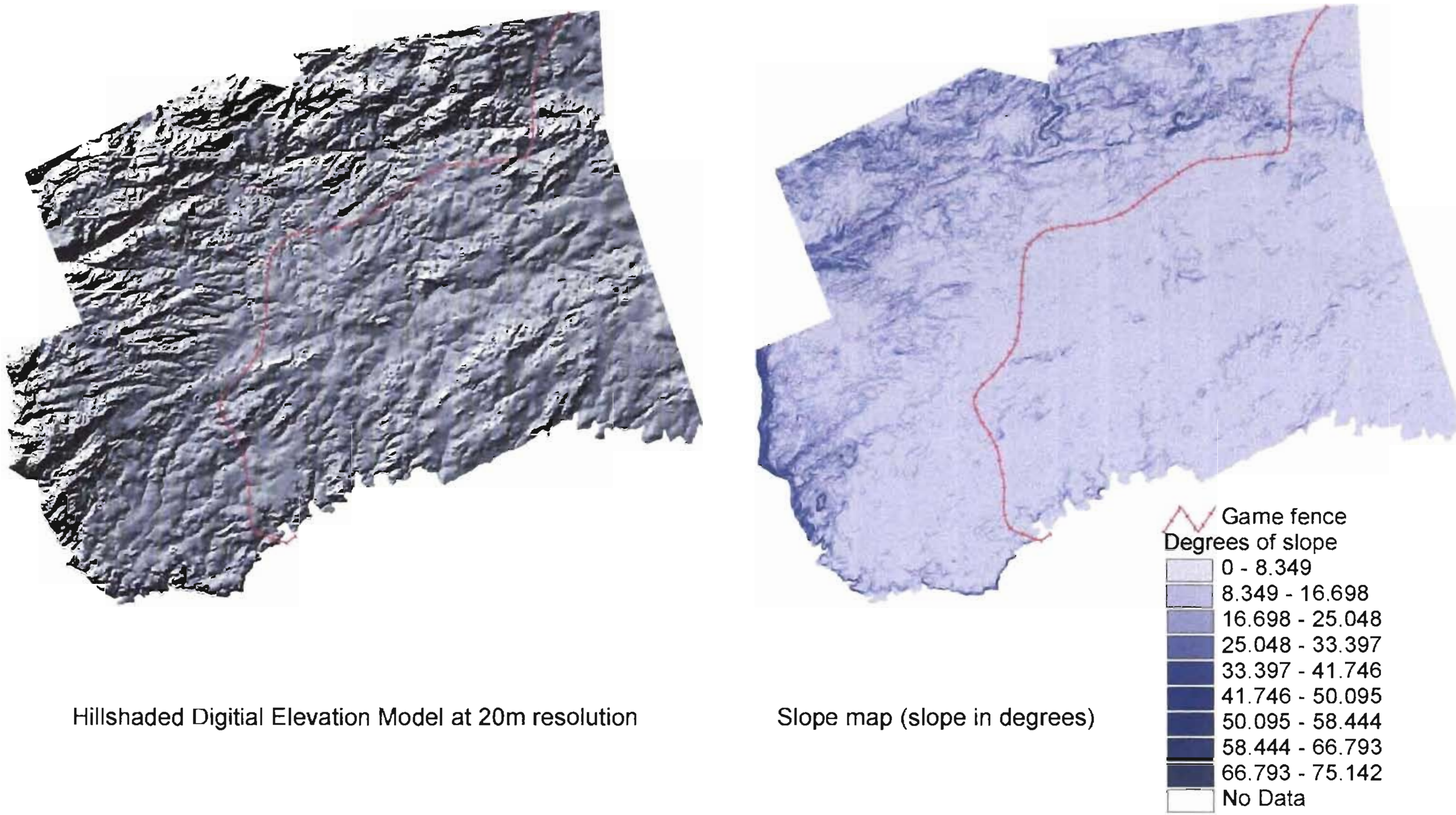


Fig 1 Location of and general features of Kanyati Communal Land



Hillshaded Digitial Elevation Model at 20m resolution

Slope map (slope in degrees)

Fig. 2 Hillshaded Digital Elevation Model (resolution 20m) and slope map of Kanyati

3.2. Landuse

Kanyati is a Communal Land, which is state land where individuals or households have tenure as opposed to private ownership. Zimbabwe is classified into five Natural Regions (based on agro-ecological surveys), where agricultural development and potential are determined by one or more natural characteristics, with rainfall being a dominant factor. These are further sub-divided into Natural Areas depending on soil and relief differences. Most of Kanyati is classified as Natural Region IV which is described as being a 'semi-extensive farming region' with a total annual rainfall of 530 - 700mm which is erratic. This region is generally considered unsuitable for dry land cropping and more suited to livestock production (Vincent *et al.*, 1956; Danley *et al.*, 1994).

The wildlife area in Kanyati falls within Natural Area XX which is classified as 'unsuitable for any form of agricultural utilisation and only suitable for nature reserves'.

The settled area is classified as Natural Area IVB for semi-extensive livestock production with cropping for stockfeed (Vincent *et al.*, 1956). Anderson *et al.* (1993) classified most of this area as 50% non-arable comprising rocky outcrops and rough, broken and stony land. The potential for arable development in the northern and western parts of Kanyati is further limited by shallow soils. Viable agriculture is restricted to valley bottoms and dispersed pockets of land in the settled area, as many areas have above average erosion potential related to long and steep slopes (Anderson *et al.*, 1993). Livestock production in these areas would also be limited even after tsetse fly eradication because of the low carrying capacity and rugged terrain (ARDA, 1987). In addition to this, the vegetation in Kanyati generally has low nutrient status and therefore poor quality forage (Huntley and Walker, 1982).

The development and utilisation of wildlife may provide an alternative to livestock as Kanyati's geographic position has the potential to develop a corridor linking the valuable wildlife resources of the lower and upper reaches of the Zambezi Valley (ARDA, 1987). A game fence erected in the early 1990's separates the north and western area of Kanyati with high terrain and relatively low rainfall, from settled area with flatter terrain and higher rainfall. It's function is disease control, separating cattle in the settled area and adjoining disease-free zone in Hurungwe Communal Land from foot and mouth disease carried by buffalo present in the wildlife area. The settled area in Kanyati A is considered to be a buffer zone between the disease-free communal lands next to it, so residents are not permitted to keep cattle here, but do so. The fence provides an opportunity to study the comparative economies of wildlife and livestock production (ARDA, 1987).

3.3. Climate

Climatic data for the area varies as there have been different assessments using Official Meteorological Dept. records, and more recently from local village development committees (VIDCO's). Mean annual rainfall was estimated by Colquhoun, O'Connell & Partners (1986) as 700-750mm, but an eight year average of records at Makande from the Dept of Meteorological Services for the period 1985-1992 was 898,2mm (Gibb &

Partners, 1993, Appendix VII). Mean isohyets produced by the Meteorological Dept. show 600-800mm of rainfall in Kanyati (also shown on a rainfall map published in 1960 by the same department). The distribution of rain within any season is erratic with high coefficients of variation (25-30%). Rainfall decreases and becomes increasingly varied in a northerly and westerly direction (ARDA, 1987). The short rainy season of 4-5 months, lasts from December to March with a 20% probability of an excessively short season. Rainfall is usually exceeded or is equal to annual evapotranspiration, although the area is affected by drought (Colquhoun *et al.*, 1986). Temperature ranges from 18 - 30°C in the escarpment and up to 35°C on the valley floor.

3.4. <u>Soils</u>

The soils are lithosols, which are shallow over weathering rock, or gravel derived from phyllites and in some parts quartzites and gneiss. There are areas of deeper soils of loamy sand to sandy clay texture in the south and eastern sections (the settled area). In the escarpment area the soils are gravelly and less than 0.25m deep, with sections of alluvial soil along watercourses (ARDA, 1987). The soils are prone to erosion as the hilly terrain causes natural soil loss to exceed soil formation rates by 5% because of the high potential for run off (Colquhoun *et al.*, 1986). The micaceous parent materials cause susceptibility to surface capping which can lead to further deterioration of soil quality (Anderson *et al.*, 1993). It is difficult to distinguish non-arable areas from arable areas based on soils because of their spatial variability as the arable areas are found in small pockets of land

(Gibb & Partners, 1993). Soil conservation practices are essential in this area for productive and sustainable agriculture.

3.5. Vegetation

The majority of the area is broad-leaved, deciduous, moist-dystrophic savanna woodland on nutrient poor soils (Huntley & Walker, 1982). It was classified by Timberlake *et al.*, (1993) as open/closed[3] miombo woodland with a predominance of *Brachystegia allenii*, *B.boehmii*, and *Julbernardia globiflora*, classified as type D7 subtype A. This is characterised by the dominance of *B.boehmii*, common flanking drainage lines and *J. globiflora* more frequent on shallow soils on slopes (Timberlake *et al.*, 1993) which was also observed on a flight over the study area in 1998. Trees generally 12-16m high with a grass layer up to 1.5m high. Termitaria vegetation (clumps of dense vegetation growing on old termite mounds) are common with pockets of riverine forest and thicket along the larger river systems (Gibb & Partners, 1993). Termitaria are an important part of miombo woodland as they are 'nutrient-rich patches within an otherwise nutrient-poor landscape' (Desanker *et al.*, 1997). They are therefore often used by birds and mammals either for food or shelter. In the lower lying areas of Kanyati to the south, and in the lower drainage systems of the Urange and Nyadara rivers, areas of *Combretum* and mopane woodland are found. Timberlake *et al.*(1993) mapped an area adjacent to Sanyati Gorge in the lower lying areas of the wildlife area as type E2: *Julbernardia-Colophospermum*

[3] Kanyati would probably be closed rather than open woodland, with canopy cover greater than 40% as opposed to less than 20% for open woodland/wooded grassland (Pratt *et al.*, 1966)

woodland catena. This is a varied vegetation type on shallow or skeletal soils characterised by an alternating dominance of *Julbernardia globiflora* and *Colophospermum mopane*.

The settled area has more extensive grasslands than the wildlife area in the upper catchments and on more developed woodlands with open grassland on the better soil (Gibb & Partners, 1993). *Hyparrhenia* species, *Heteropogon contortus* and *Diheteropogon amplectens* are co-dominant grass species in the open drainage lines and *Brachiara* species associated with mopane woodland (ARDA, 1987).

A burning programme accompanied tsetse control hunting in the Zambezi Valley, for the purposes of preparing ground for spraying with insecticides, which involved frequent burns in the early dry season. Regular burning early in the dry season in areas with low rainfall and soil fertility may cause bush encroachment, reducing perennial grass cover (Child & Riney, 1987). The intensity, timing and frequency of fires determines their impact on miombo woodland, where late dry season fires are more intense and destructive than early dry season fires. If late dry season fires occur frequently the woodland can change to open, tall grass savanna with scattered fire-tolerant canopy trees and shrubs (Desanker *et al.*, 1997). In Kanyati, however, results from study by Cumming *et al.* (1997a) do not indicate significant opening up of woodlands in the wildlife area.

3.6. Wildlife

In spite of the area having the potential (in terms of habitat) to support wildlife populations, there are low densities of animals partially because of tsetse fly control hunting operations which took place in the escarpment area from 1952 to the early 1970's (Child & Riney, 1987). The most intensive hunting occurred from 1952-1960 in the escarpment area of Kanyati, when 17 881 large mammals (from 23 species) were shot. This yielded on average 62.5 tonnes of edible species annually, of which 40 tonnes was estimated to be sustainable take-off (Colquhoun *et al.*, 1990). The tsetse control hunt records show that during the 1953-1960 hunting period: 38% of the species killed were duiker (*Sylvicapra grimmia*), 17.3% were warthog (*Phacochoerus aethiopicus*), 10% were baboon (*Papio ursinus*), 9.8% were bushpig (*Potamochoerus porcus*) and 6.8% were kudu (*Tragelaphus strepsiceros*). The hunting of elephant (*Loxodonta africana*) and buffalo (*Syncerus caffer*) continued into the late 1960's, for example 300 elephant were reportedly shot in 1967/8 alone (Lovemore in Colquhoun *et al.*, 1990).

Miombo woodland is characterised by low biomass and low levels of consumption by indigenous large herbivorous mammals compared to other African ecosystems with similar mean annual rainfall. This is due to the generally low nutritional quality of foliage. The majority of herbivore biomass in miombo comprises elephant, buffalo and selective grazers such as Lichtenstein's hartebeest, sable and roan antelope (Desanker *et al.*, 1997). Table 3 shows estimates of species numbers from fieldwork in 1993, as well as WWF aerial surveys. Very few of the larger ungulates were reported in 1993 in the settled area, other than a few zebra, kudu and bushbuck near the game fence and Kanyati River. Elephant activity was noticeable near watershed trails, upper catchments and between river systems (Gibb & Partners, 1993). CAMPFIRE records of quotas and dividends received from safari operators in the area show that elephant, buffalo, eland, sable, zebra, klipspringer, baboon and birds such as guinea fowl and francolin, have been hunted in the area since 1994 (Nyaminyami Rurual District Council annual reports) The two wards in Kanyati are receiving dividends from trophy hunting in the area through CAMPFIRE.

The area could form an important wildlife corridor between neighbouring Matusadona National Park and Charara Safari Area, through the south western area of Kanyati where the southern end of the Sanyati Gorge, which separates Matusadona and Kanyati, can be traversed by wild mammals (D. Cumming, R. Taylor, 1998; personal communication). This would result in increased gene flow between these two areas and would also help conserve a relatively pristine area of miombo woodland (one of the last areas of its kind in the Zambezi Valley). The area designated for wildlife constitutes 62% (Gibb & Partners, 1993) of the whole area and is manned by two game guards by the Nyaminyami Wildlife Management Trust. Kanyati and Gatche-Gatche have benefited from revenue generated by utilisation of wildlife mostly in Omay Communal Lands up until 1993, through the CAMPFIRE programme. Up until this time they had received more dividends from wildlife-based tourism ventures generated outside Kanyati Communal Lands than within.

Poaching from residents in the area and by people from neighbouring communal lands has contributed to low animal densities in the area (ARDA, 1987; A.Gardiner, 1998, personal communication from observations in the area). Poaching using firearms was seen as a direct result of squatters in the area, 'unheard of in the early 1990's' and anti-poaching operations were recommended (Nyaminyami Rural District Council annual reports; Ferreira, 1995).

High densities of elephants existing in an area for a long period of time alters the woodland, generally reducing large trees and increasing grassland and shrubland, such as has happened in miombo woodlands in the Zambezi escarpment area over a period of twenty years. Cumming *et al.* (1997) found that woodland structure changed, such as a decrease in canopy tree diversity in areas where elephant activity had occurred at densities of over 0.5 per km sq. They also found a reduction in the diversity of bird and insect species diversity where the tree canopy had been removed by elephant, compared with similar areas with intact woodlands. This study included a comparison the state of woodland, bird, bat and insect populations in intact (very little elephant activity) and impacted (high elephant densities) miombo woodlands. Elephant activity can increase the probability of more frequent and intense fires in woodland by increasing grass production through the removal of woody plants (Desanker *et al.*, 1997). Elephants may also have a particular impact on *Brachystegia boehmii* (found in Kanyati) by damaging them sufficiently to allow insect and fungus attacks (Thomson, 1975). Hence the miombo vegetation in Kanyati could be modified to more open woodland and grassland by high densities of elephants.

Table 3 Animals sighted in Kanyati

ANIMAL	Estimate	Comments
buffalo	393 introduced in 1991[4]; 100 est., 0.23 km^{-2} in 1993 [5]; 16 est., 0.2 km^{-2} in 1995 [8]; 6 est., 0 km^{-2} in 1997 [8]	Poaching estimated to negate annual increase of 10-20%[6]. Herds of 85 animals sighted in 1995[7]
black rhinoceros[6]	7 in escarpment in 1990 [6]	All have disappeared
bushbuck	0 est., 0 km^{-2} in 1997 [6]	Present in escarpment but spoor lacking in suitable habitats [4]
bushpig [6]	spoor throughout	Along river systems adjacent to Kanyati settlement area
duiker [6]	common throughout	
eland	spoor throughout, 3 seen [6]; 0 est., 0 km^{-2} in 19978 [8]	Migratory population, not common, good herds reported in '95[7]
elephant	96 est., 0.22 km^{-2} in 1993 [5]; 158 est., 0.3 km^{-2} in 1995 [8]; 6 est., 0 km^{-2} in 1997 [8]	
grysbok [6]	common throughout	
hyena [6]	spoor throughout	Escarpment area and lowlands
impala	1000 introduced in 1991 [4]; 0 est., 0 km^{-2} in 1997 [8]	Poaching control should result in population increases.
kudu	spoor throughout [6]; 0 est., 0 km^{-2} in 1997 [8]	Good trophy bulls seen in upper Gatche-Gatche river system [6] (Kudu seldom seen from the air in aerial surveys)
klipspringer	hunt records	Small numbers in '94 and '96 (Nyaminyami RDC records)
lion	one hunted in 1995[7]	Reported to move through the area [6]
leopard [6]	unknown	Spoor seen often
sable	120-175 [6]; 0 est., 0 km^{-2} in 1993[5]; 33 est., <0.1 km^{-2} in 1995[6]; 60 est.,0 km^{-2} in 1997 [6]	Ideal habitat, good herds reported in 1995[7]
small mammals [6]	spoor, hole digging, root & termite foraging evident	Terrain diversity indicated an equally diverse bird-life with some rarities occurring
reedbuck [6]	none	Habitat suitable in grasslands and vleis, could be introduced
warthog [6]	10	Rare, absence due to tsetse hunting, and hunting dogs
waterbuck	0 est., 0 km^{-2} in 1993 [5]; 81 est., 0.9 km^{-2} in 1995 [8]; 0 est., 0 km^{-2} in 1997[8]	Good healthy population [6]
zebra	few small groups; 0 est., 0 km^{-2} in 1993 [3]	Very suitable habitat, good herds reported in 1995[5]

[4]Translocation of 393 buffalo and 1013 impala via Gatche-Gatche in 1991 (Taylor, 1998, pers.comm.)

[5] Cumming, Taylor & Mackie (1997): from aerial census for 1993, Kanyati wildlife area only

[6] Gibb & Partners(1993): brief field survey

3.7. Demography

Settlement started in the area in the 1970's but the largest influx of people was during the period 1983-1987 (ARDA, 1987; Gibb & Partners, 1993):

Table 4 Number of households in Kanyati 1982 - 1992

year	1982	1983	1984	1985	1986	1987	1992
number of households	61	240	450	670	805	1050	1598

Of the households counted in 1987, 180 were absentee households from other areas who wanted to be allocated land. The Rural District Council therefore put the number of resident households at 870 in 1987. Total population was estimated to be 8513 from 1992 census, of which 53% were women. Gibb & Partners (1993) described the relatively low percentage of female-run households compared with the national rural average of absent husbands, as an indication of the commitment to farming of Kanyati plot holders, and the viability of farming in the area.

3.8. Culture

There are many cultures in the area as the people originate from many different places. The majority is from Masvingo Province (45%) whose ethnic group are the Karangas,

[7] Ferreira (1995): observations in the area
[8] Mackie (1995 & 1997): from aerial census, Kanyati wildife area only.

with the next largest group coming from Mashonaland West (19%) namely Hurungwe, Kariba and Chinhoyi. The average length of residence in the area was 8 years with a range of 1 to 14 years (Gibb & Partners, 1993). There are therefore diverse skills for cropping and husbandry employed. None have long-term experience of agriculture in the area so may be more open to adopt new landuse practices, but are generally not accustomed to wildlife utilisation as a land use as they originated from densely populated areas such as the communal lands in Masvingo (ARDA, 1987).

3.9. Infrastructure

- More than one junior school, senior school and several buildings in Makande.
- No electricity for the most part, one diesel generator at Makande, some households have solar power.
- 15 functioning boreholes in 1991 with some still under construction, and 5 dams since 1990 (with one still being constructed in1995).
- Many access roads and tracks.
- Game fence (Foot and Mouth Disease or buffalo exclusion fence) constructed during the period 1989-1992.

(Gibb & Partners, 1993, A. Gardiner, 1998 personal communication)

Kanyati provides a unique opportunity to investigate patterns of land cover change with different land use as it is divided into a wildlife and settled area by the game fence. The wildlife area and comprises prime miombo woodland which has not yet been used to its full potential for wildlife utilisation under CAMPFIRE. It may also constitute an important wildlife corridor with the potential for enhancing genetic flow between wildlife in Omay Communal Lands and Charara Safari Area and Hurungwe Communal Lands in the east. There was a dramatic increase of people into the area from 1983 to 1987 with subsequent increase in cultivation and settled land. This is indicative of the broader problem of increased pressure on land in the communal lands in Zimbabwe as human populations increase.

4. METHODS

4.1. Research design

4.1.1 Study site selection

This study initially intended to investigate and compare land transformation patterns in several communal lands with similar soil, vegetation and topography, and varying population densities. Several communal lands in the Zambezi Valley were considered using overlays of broad vegetation and soil types, population density and agro-climatological regions of Zimbabwe. The analysis of more than one communal land was considered to be too ambitious for the scope of this project in terms of time, especially with the amount of aerial photograph interpretation that it would have required. Kanyati Communal Land was chosen as it provides an opportunity to compare land transformation patterns in the wildlife area and settled area. The wildlife area has prime miombo woodland and could form an important wildlife corridor between Omay Communal Lands and Charara Safari Area (R.Taylor, 1998, personal communication; ARDA, 1987).

4.1.2 Time periods

The time window chosen was over a 20 year period, 1973 (after start of settlement in the area) to 1993, and for availability of aerial photographs at the same scale (1:25 000) . The aerial photographs were also taken in the same season, in the dry, winter period from

June to August of the two years. Drought periods between 1973 and 1993, were in 1981/82 and 1991/92. The 1973 aerial photographs show Kanyati before settlement had occurred and 1993 photographs show the area after extensive settlement and cultivation.

4.1.3. Spatial Units of Analysis

The smallest unit of analysis, the patch or individual spatial element, is an area which is relatively homogeneous with respect to texture and tone on the aerial photograph, distinguishable from its surrounds. The size of the smallest identifiable feature was determined by the granularity of the aerial photographs used. Patches vary in size depending on the scale of the study but are generally several square meters (<$100m^2$). For the purposes of this study the 'patches' identified were essentially individual spatial elements which also included areas up to approximately 100 square kilometres. In the case of the dominant land cover type, the matrix, the separate spatial entities were much larger, the maximum being almost 480 km^2. Analysis of different extents occurred but the resolution of the base data did not change. The next unit of analysis was the land cover type which comprised many patches as separate geographic features. The largest unit of analysis was the entire area or landscape comprising several land cover types.

4.2. Data capture

4.2.1. Land cover types

Particular textures, tones and patterns on the aerial photographs defined the land cover types. They were identified using stereo-photograph interpretation and directly marked onto every second stereo-photograph pair. In cases where a photo-interpretation survey covers more than three contact prints, alternate contact prints are annotated only (Carver, 1981). Table 3 and Figures 3 - 6 show the 'footprints' or defining characteristics of each land cover type. They were refined and some were subsequently discarded as they proved to be difficult to identify consistently. An example is the riverine vegetation identified and mapped but later rejected as the areas could not be mapped consistently. This land cover type comprised woodland fringing watercourses which were difficult to distinguish from miombo woodland bordering rivers, in areas under shadow (because of steep slopes) as the detail was obscured by the dark tones. In most cases the areas were also too narrow to map as areas as opposed to lines. A preliminary comparison of 1973 and 1993 riverine vegetation identified showed very little to no spatial correlation. This indicated that either the majority of riverine vegetation present in 1973 had disappeared in these areas by 1993 or misinterpretation of this land cover type had occurred. The former scenario is highly unlikely especially in the wildlife area where there did not seem to be much change in the vegetation over the twenty-year period. It is far more likely that the method of aerial photograph interpretation did not consistently identify this land cover type satisfactorily. Riverine vegetation was more easily identified from a low-level flight in a light aircraft over the study site in 1998.

The boundaries of the cultivated, settled and cleared or grazed areas were more readily identified than the woodland cover types, because of distinct boundaries around relatively regular geometric shapes. The woodland cover types had boundaries, which were not clear-cut (often described as fuzzy boundaries), as is often the case with vegetation types. They were characterised by a gradation of change in the 'footprint' of a land cover type over an area, as the patterns of clumped vegetation forming part of these footprints were relatively diffuse. The vegetation map by Timberlake *et al* (1993) for the north-eastern communal lands in Zimbabwe shows that Kanyati has two main vegetation types: miombo woodland (type D7) and miombo-mopane woodland (type E2). Using the boundary separating these two types of woodland, an attempt to distinguish between the two purely from the 1993 aerial photographs, proved to be unsuccessful. It is impossible to map (relatively objectively) different vegetation communities in any detail only from aerial photographs in Kanyati, although this may be feasible in many other areas. This would require considerable experience and extensive botanical knowledge of the area on the ground. This would negate the advantages of using remotely sensed data instead of detailed and labour intensive and time-consuming field surveys. Therefore only broad vegetation types within miombo woodland were identified, with the categorisation of specific plant communities within these such as those with termitaria patterns. Broad vegetation types rather than detailed vegetation types could be consistently identified and mapped in this study, using patterns of tone and texture.

Termitaria were clearly visible from aerial photographs as regularly spaced, circular clumps of dense vegetation and they are often used as field diagnostic features (Tinley, 1977). These are formed by hill-building termites and are covered in well-developed vegetation growing on the characteristic mineral nutrient-rich and clay soils. The soils have much higher mineral nutrient content and higher pH, clay, silt and fine sand content compared with surrounding soils) as the termites bring saline, clay subsoils to the surface (Watson, 1976, Tinley, 1977). The vegetation and soils in these patches differ distinctly from surrounding areas and form nutrient-rich islands within the relatively nutrient-poor landscape of miombo woodland (Desanker *et al.*, 1997; Tinley, 1977). Bird species use termitaria for perch sites and food, for example Heuglin's Robin (*Cossypha heuglini*) and White-throated robin (*Cossypha humeralis*) frequent termitaria as well as other thicket habitats (Irwin, 1981).Animals deposit seeds (especially of fruit-bearing species) when utilising the termitaria, which then provide concentrations of these species on the mounds. They provide forage, shelter, shade and minerals to large mammals and where elephant have excavated the soils, watering sites are sometimes created (Ruggiero and Fay, 1994). Pans are formed from termitaria by large mammals by eating the vegetation and digging, and are further enlarged by their wallowing once water is present (Tinley, 1977). Cleared termitaria were also visible from aerial photographs but these were not filled with water, as the vegetation had simply been removed either by elephant or fire activity, or a combination of both.

Termitaria are also used by farmers because of the nutrient-rich soils, but repeated cultivation kills off the colonies of termites (Tinley, 1977).

Table 5 Defining characteristics of land cover types

Code	Land cover	Tone	Texture	Site	Vegetation	Other
CULT	cultivated land	usually light tones but can vary	smooth, fine, uniform, sometimes evenly corregated	near huts, rivers and tracks	occasional tree or clump of dense vegetation. Fallow or cropped land	Geometric shapes, easily identified.
SETT	settlement	uniformly dark circles or squares on bright white surrounds	clumped, regular patterns	near cultivated land	none, usually surrounded by cleared land, the radius of which varies	Huts, outhouses, buildings. Easily identified in spite of small size.
GRAZE	grazed/cleared land	white to pale grey background with mottled greys of remaining vegetation	irregular, fine patterns of remaining vegetation, area of cleared vegetation have smooth and uniform texture		Less than 40% cover of woodland, the rest cleared of almost all vegetation leaving clumps of trees and shrubs	Difficult to distinguish these areas where decimation of woodland is not as severe as in other areas.
MIOMBO	miombo woodland matrix	grey substrate varying in shade with darker shrubs and trees. Darker tones with recently burnt woodland	relatively uniform, fine patterns of trees and shrubs	most widespread land cover type	miombo, miombo/mopane woodland	sometimes difficult to distinguish from woodland with termitaria types
WDTa	woodland with termitaria type A	pale-grey/white substrate with very dark clumps of termitaria	regularly spaced, dispersed, large circular termitaria on a fine, smooth substrate/matrix	generally in lowland areas	miombo, miombo/mopane woodland with termitaria	Exact boundaries difficult to distinguish from matrix woodland because of diffuse clumping pattern. More easily identified than WDTb
WDTb	open woodland with some termitaria	mottled greys with white, dark clumps which vary in tone	irregularly spaced, clumpls of vegetation with a rough, irregular textured substrate/matrix		miombo, miombo/mopane woodland possibly with some termitaria	Exact boundaries difficult to distinguish from matrix woodland because of similarity to it. Identification not reliable or easily replicated
WDTc	woodland with cleared termitaria	grey substrate with small, white, circular clearings	uniformly smooth, fine substrate, sieve-like pattern of clearings	Mid-western section of wildlife area: escarpment	miombo, miombo/mopane woodland with cleared termitaria clumps	Removal of termitaria vegetation may indicate elephant activity, or a combination of fire and elephant activity
RIV	riverine vegetation	dark, mottled, sharp boundary	rough, dense, clumped (trees)	bordering rivers and streams	usually well-developed crowns, large trees, dense vegetation, more than 70% cover of trees	Difficult to identify because of shadow and often too narrow to constitute a polygon rather than a line. Was omitted from analysis because of unreplicability in identification

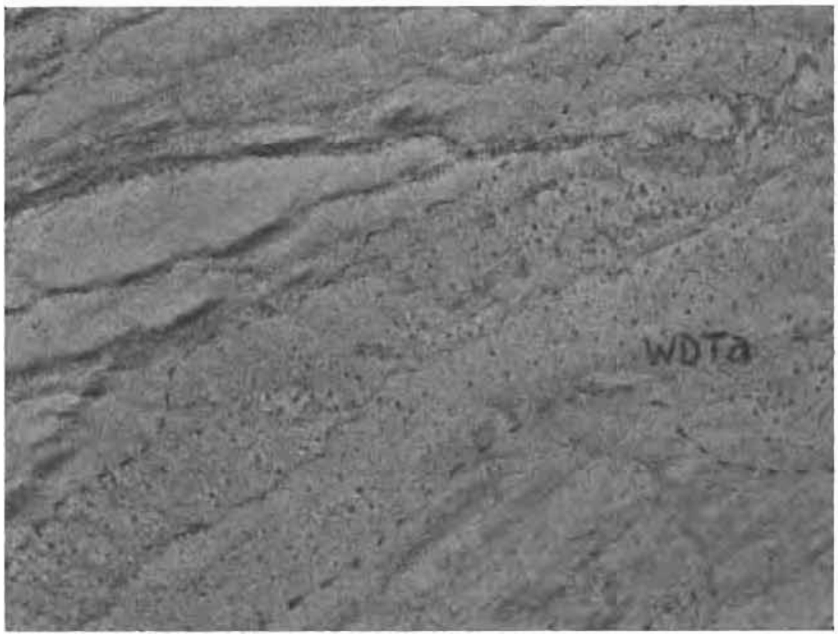


Fig. 3 Aerial photograph showing woodland with termitaria pattern A

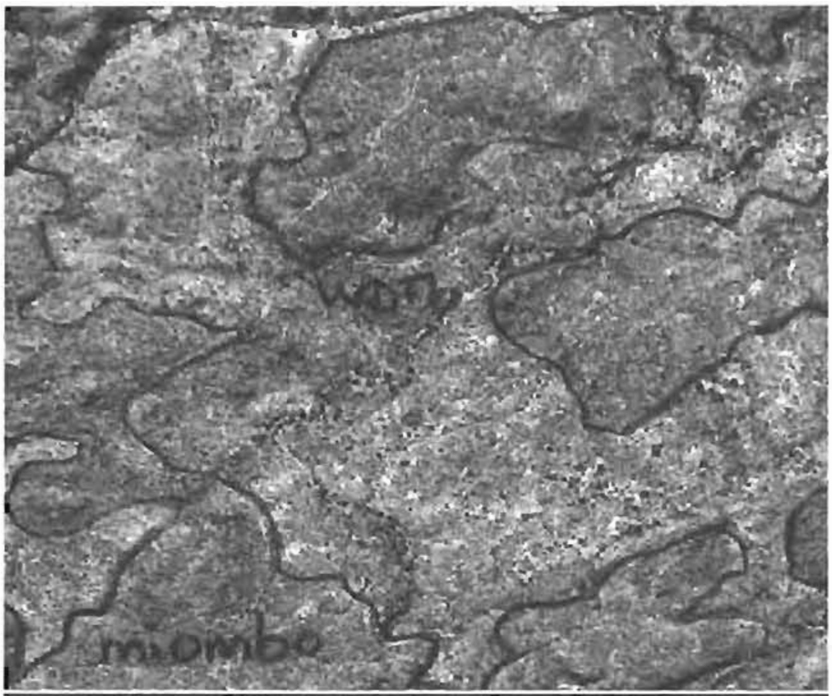


Fig. 4 Aerial photograph showing open woodland with termitaria pattern B and miombo woodland

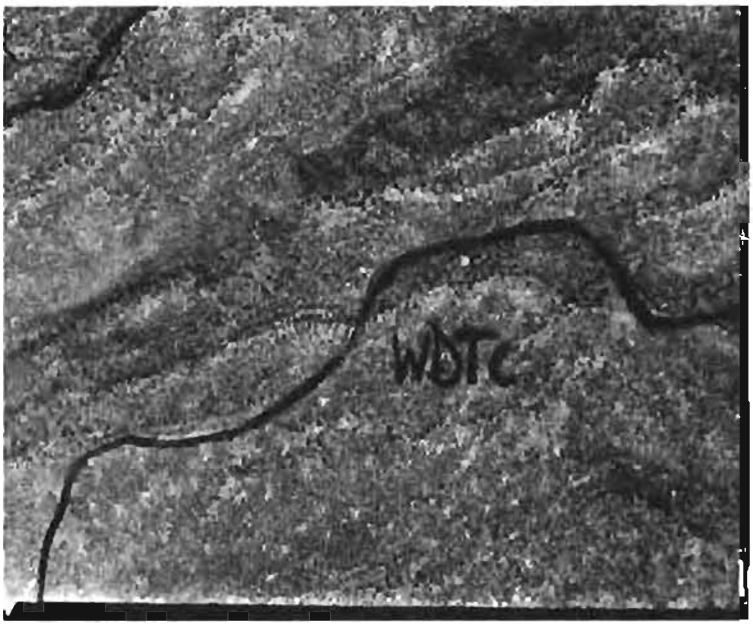


Fig. 5 Aerial photograph showing woodland with cleared termitaria *(clearer in bottom left corner showing cleared, circular patches)*

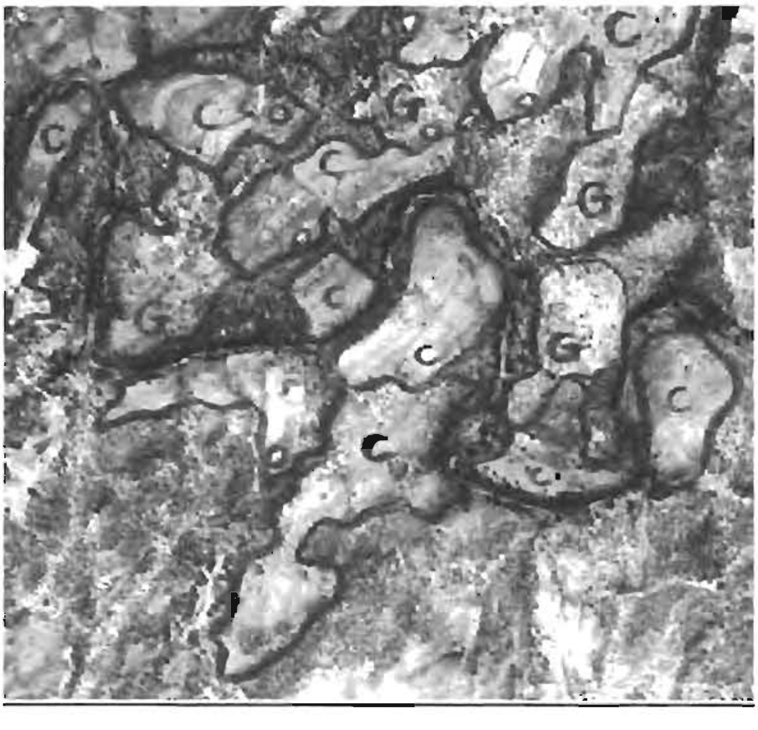


Fig. 6 Aerial photograph showing cultivated ("C"), grazed/cleared ("G") and settled land *(small circular features within cultivated or grazed land)*

4.2.2. Manual photo-interpretation vs. Automated classification

The method of manually interpreting aerial photographs by eye was chosen as opposed to automated classification by processing scanned images of the photographs for the following reasons:

- Automated classification of several scanned images of aerial photographs of the study area was not satisfactory. There was considerable overlap between classes as finer texture differences within areas of similar tones were not identified. Areas in shade or with a darker tone (which occurs quite often with photographs captured at different times) resulted in different cover types being distinguished.
- Every second stereo-photo pair would have to be scanned and processed which would have been too time-consuming considering that there were about sixty aerial photographs per time period. This would have included time and computing power needed to process, georeference, and edge-match merged images.
- Every scanned image would require at least six control points to be identified for simple georeferencing without correcting for geometric distortion. Even such basic georeferencing would have been difficult as the majority of the wildlife area did not have many features to be used as ground-control points, such as river and track intersections or buildings, especially the 1973 photographs.

Hudak and Wesselman (1997) successfully identified land cover types and their change with time using a textural analysis of scanned photo-images in semi-arid to arid rangelands in Bophutatswana, South Africa. A textural index was used to characterise bush densities across two landscapes. However their study sites were larger than Kanyati and 1:50 000 digital vegetation and land use maps were used to provide zonal boundaries and ground control points first. Similar maps at this scale are not available for Kanyati. The ArcInfo function they used calculates the standard deviation of pixels within a filter window to produce a textural index (A. Hudak, 1997, personal communication). This method was found to be unsatisfactory in identifying the land cover types from the scanned aerial photographs of Kanyati. This was because the land cover types were not reliably and consistently identified especially in areas of shadow and darker toned aerial photographs.

4.2.3. <u>Use of aerial photography vs. satellite imagery</u>

Satellite imagery would be preferable to using aerial photographs as it is usually already in digital format and georeferenced. Unfortunately the use of satellite imagery was considered to be prohibitively expensive and not available earlier than the mid-1980's. LANDSAT imagery at a scale of 1:50 000 at best was only obtainable for the mid-1980's to 1992. The use of panchromatic SPOT images (10m resolution) available at an affordable price was considered, but these are not suited to automated image interpretation because they have no colour bands and composites. It also would not have been possible to analyse a trend over a decade as the only images available were from the early 1990's. These images were used to check the position of some geographic features identified on the aerial photographs. The use of aerial photographs was therefore found to be more appropriate than satellite imagery in this study, as they were available at a fine scale and covered a longer time period, from the early 1970's to 1993.

4.2.4. Transferral to digital georeferenced data

4.2.4a Land Cover Types

A Planvariograph machine was used to transfer the land cover types demarcated on the aerial photographs onto orthophotographs of the same scale (1:25 000). The Planvariograph projected an image of the aerial photograph onto the orthophotograph, which was manipulated (the image of the aerial photograph) until it was superimposed at the same scale as the orthophotograph. The river features were used to orient the aerial photograph on the orthophotograph. The orthophotographs were prepared as Sepia prints by the Surveyor General's Department in Harare. These are printed on a more stable form of material than paper for digitising (a type of plastic). They comprised georeferenced orthophotographs with rivers and contours.

The land cover types were traced onto the orthophotographs and then digitised from these using Atlas-GIS, a vector GIS package that employs a simple, non-topological data format. Permission was obtained from the Surveyor General's Department to digitise this data with the proviso that it be used for research purposes only. A co-ordinate system using Universal Transverse Mercator projection was defined, using zone 35 and Clarke 1880 ellipsoid. The maximum root mean squared (RMS) error was recorded for each session of digitising. The RMS error is a measure of the control point registration accuracy during digitising and coverage transformation (ESRI, 1990). The maximum RMS error for the land cover type coverages was 0.909 metres. The attributes of each geographic feature were the land cover type code and the orthophotograph sheet code.

Once the land cover types were in a GIS format the features were checked for areas of overlap and mis-identification. In some cases the original aerial photographs were consulted and coverages edited accordingly as there was some mis-classification between woodland with termitaria types A and B.

The use of an analytical stereoplotter to transfer land cover types from aerial photographs directly into digital georeferenced format, was considered but this would have been extremely time-consuming for the high number of aerial photographs required in this study. This procedure is highly accurate but relatively complicated and was not considered necessary for the purposes of this study (S. Binedell, S. Mason S., 1998, personal communication[9]). This also would have required a Digital Elevation Model which had not been created at that time.

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The miombo woodland matrix was not digitised but created in Atlas-GIS by disaggregating the study site boundary using the other land cover type features as 'islands'. The 1993 matrix took considerable time (approximately 100 hours) due to the complexity of the coverage and software limitations. The maximum number of vertices per features is limited to 4000 in Atlas-GIS so the woodland matrix was created in segments, exported to ArcView (v. 3.0) and then contiguous segments aggregated. ArcView did not have a facility to disaggregate the features of an entire theme by another, but rather on a feature level only. One polygon can be used to split another at a time, or a line can be digitised on-screen which splits all polygons it traverses.

4.2.4b Rivers

River and stream features were digitised from the orthophotographs using Atlas-GIS. The attribute features included the name and stream order. The maximum RMS error was 0.927 metres.

4.2.4c Elevation

The contour lines were digitised from paper topographic sheets at a scale of 1:50 000, as the lines were extremely dense on the 1:25 000 orthophotographs due to the steep terrain of the study site. The contour intervals were 20 metres but in very steep areas every second contour line was digitised (40 metre interval) as the lines were too close together to digitise separately. The maximum RMS error was 8.34 metres.

The disadvantages of scanning the contours from the topographic sheet outweighed the advantages. The 'z' values (height) would still need to have been manually assigned or possibly semi -automated with vectorising software. The scanner available was only capable of scanning A3 size, which would have required considerable edge matching and georeferencing of scanned images for each topographic sheet.

4.2.4d Tracks

Tracks from the 1:50 000 topographic sheets were digitised to verify positions of tracks identified on aerial photographs. The topographic maps were compiled by the Surveyor General in 1976-1978 (they have not been updated since). The maximum RMS error was 8.20 metres.

4.2.5. Ground-truthing

There are two components to ground-truthing: locational where the accuracy of geographical positions is assessed, and classification where the identification of land cover types is validated. There is also a temporal consideration as the land cover types identified in 1973 cannot be ground-truthed as these have changed, so ground-truthing would be restricted to those land cover types that can be consistently recognised (Avery, 1968). This would involve checking positions and land cover identifications. Given that the woodland land cover boundaries are not clear cut this would be a difficult task. Burrough (1986) recommends against spending large amounts of time assessing the exact location of a soil or vegetation boundary or to represent such boundaries with a high degree of artificial accuracy, as it would be wasted because these boundaries are usually 'fuzzy' gradations rather than distinct borders. Ground-truthing of digital contour coverages was considered to be unnecessary as this data is secondary (from topographic maps) and comprises interpolations between spot heights.

Aerial reconnaissance of the study site and surrounding areas was carried out in March 1998 with Mr C. Mackie, a wildlife management specialist in WWF. This was useful in assessing land cover identification from aerial photographs, especially woodland with termitaria.

4.3. Analysis

4.3.1. Measurement of spatial pattern and trends

The land cover type coverages were exported to ArcView 3.0 shape files for analysis. The area and perimeter measures were calculated (in projected metres) as the map units in the theme attribute tables were in "native" map units.

The fractal dimension was then calculated in the theme attribute tables using the formula:

$$2 \times (\log [\text{Perimeter}])/(\log[\text{Area}])$$

Two other shape indices were also calculated, from Hulshoff (1995):

$$S1 = \frac{1}{N_i} * \sum \frac{Perimeter_i}{Area_i} \text{ (calculated per land cover type)}$$

where N_i = number of patches of category i

This measures the mean perimeter:area ratio of a land cover type, where a relatively high value represents many patches with small interiors.

$$S2 = \frac{1}{N_i} * \sum \frac{Perimeter_i}{4\sqrt{Area_i}} \text{ (calculated per land cover type)}$$

S2 measures the deviation of average deviation of patch shape from an isodiametric patch (circular or square) which contains the most patch interior. It is a measure of complexity of shape.

Summary attributes were calculated for each theme: number of patches (geographic features); total, range, average and standard deviation of areas and fractal dimension values. These measures could then be compared between the two time periods.

In order to analyse the spatial pattern of land transformation, the shapefile themes were converted to grid themes, after copying all land cover types into one theme per time period. Grid themes are raster images with attached attributes, and allow for a greater range of analysis within the ArcView Spatial Analyst extension. The areas of 1993 land cover types falling within 1973 land cover types were calculated using the Summarise Zones function. This was to ascertain how land cover types had been transformed after twenty years, for example the percentage of miombo woodland matrix, which had changed to cultivated land in 1993.

There were often discrepancies between the areas measured in the grid themes and those in the shape themes. When vector data is converted to raster data topological detail is often lost (as everything is converted to pixels) but areas of overlap in the vector data disappear. The area estimates of the grid themes, were used as they most closely approximated the total area of the study site as measured in vector format.

The measures of pattern from the GIS were analysed in a spreadsheet program.

4.3.2. Slope and river analysis

People utilising miombo woodland tend to do so in a 'fine-grained manner' in that they use pockets of land with higher fertility such as in river valleys (Desanker *et al.*, 1997). To investigate the proximity of land cover classes to primary rivers and spatial distribution with slope, appropriate analyses occurred. Main rivers (first and second order) were selected and buffers created at distances of 1, 2 and 5 km away from them in ArcInfo. The area of each land cover type within each buffer was calculated in ArcView for both years and analysed. In ArcInfo a Digital Elevation Model was created from the contours, using the TOPOGRID method (as opposed to using a Triangulated Irregular Network) at 20m resolution. This was exported to ArcView and a slope map created which was then reclassified into 7 classes of degrees of slope. The area of each land cover type within each slope class was calculated.

4.3.3. Change in extent: wildlife and settled area analysis

In order to create separate vector coverages of the land cover types in the wildlife and settled areas; the data was disaggregated using the game-fence in Atlas-GIS. These were exported into ArcView and the land cover types combined into one theme per area (wildlife and settled). Grid themes of the wildlife area and settled area matrix themes were created using addition overlays. Areas of intersection between 1973 and 1993 coverages were calculated

4.3.4. Likely effects on key species

The likely effects of patterns of land cover change on key large herbivore species were investigated by using their spatial requirements. A literature review provided information on the habitat type and home ranges of these species. The key species chosen were buffalo, bushbuck, elephant, kudu, sable, waterbuck and zebra. These species were chosen as they are found in Kanyati and their habitat requirements suit the miombo woodland of the area. Miombo woodland has low nutrient status so that low biomass tolerant herbivores such as elephant, buffalo and zebra, are ideally suited to this area (Bell, 1984). Other large herbivore species, such as impala and wildebeest were considered but were not used, as the habitat in Kanyati was generally unsuitable. The species chosen are also important in terms of their potential for generating income through CAMPFIRE ventures in the area. In some cases it was difficult to fit the habitat requirements from the literature with the land cover types identified in this study.

A simple habitat suitability map was created for each species using land cover types, slope and water availability coverages, for 1973 and 1993 for the whole of Kanyati. Each coverage was reclassified according to the preferrences of each species, except for the slope image which had the same classes for all species. This comprised 4 classes:

0 = > 60 degrees

1 = 30 to 60 degrees

2 = 9 to 30 degrees

3 = 0 to 9 degrees

The land cover types were reclassified as Boolean images and remained the same for all species, but changed for the two years, with the exclusion of cultivated, grazed/cleared and settled land in all cases. Additional Boolean images were created for preferences for certain species comprising open woodland for the two years. The identification and mapping of waterpoints during the dry season in 1973 and 1993 occurred using information from various sources and the aerial photographs (Colquhoun *et al.*, 1986; ARDA, 1987; A.Gardiner, 1999, D. Cumming, 1999; personal communication). Distances from these waterpoints for 1973 and 1993 were computed using buffers, and images of particular distances (such as 5 km in the case of sable) were created from these. Instead of assigning Boolean values to these images, such that 0 would denote more than a specified distance from waterpoints and 1 within the specified distance, values of 1 and 2 were assigned respectively. This was because the habitat suitability maps were created by multiplying the suitable land cover, slope and water availability coverages, which meant that values of 0 for water availability would render these areas inaccessible as the overall value would be 0. This was considered to be unsatisfactory as the animals would still be able to traverse these areas, but suitable habitat for feeding would be found within a certain distance from water. Areas with values of 0 for inaccessible land cover (such as cultivated land) or very high slopes remained with those values. This would not have been the case if the images were created using addition overlays, and served to provide a form of weighting for cell values. Habitat preferences for certain species, such as preference for open woodland in the case of sable and buffalo, were added rather than multiplied. This was to reduce the effect of these images on the multiplied overlays. Therefore in areas with open woodland, a value of 1 was added to each cell value, as opposed to multiplying them by 1 or 2. Multiplying by a value of 1 would have no effect with an accompanying significant and erroneous effect of multiplying by 0 for those areas which were not open woodland. This would mean that these areas would be inaccessible and unsuitable habitat, rather than habitat that was simply not preferred. Multiplying by a value of 2 for areas with open woodland and 1 for other areas, served to increase the sizes of all classes of habitat suitability for those species with this preference specified. In this case the classes for those species without an additional habitat preference, were much smaller. This would mean very different sized classes would result between species, which was not the case if the preference images were simply added rather than multiplied.

It should be recognised that the exclusion of cultivated and grazed/cleared land in the habitat suitability maps, identified as inaccessible, is not absolute as some species occasionally venture into these areas, particularly at night. Elephant and kudu are prime examples, but these areas were excluded because local communities living in these areas, actively try to prevent these species from entering their fields.

The habitat suitability maps for each species were created using different images based on habitat requirements and waterpoints for the dry season. Buffers were created around waterpoints and the game fence for analysis of distance from these features. The images used to create the habitat suitability maps are detailed below, excluding the slope image used for all species.

4.3.4a Buffalo

- Images of suitable land cover were identified as all woodland categories with the exclusion of cultivated, grazed/cleared and settled land, for 1973 and 1993.
- Images of areas < or equal to 10 km (value of 2) and > 10km (value of 1), from waterpoints in the dry season were created for 1973 and 1993.
- Additional preference images of open woodland with termitaria type B were created for 1973 and 1993.

4.3.4b Bushbuck

- Images of suitable land cover were identified as all woodland categories with the exclusion of cultivated, grazed/cleared and settled land, for 1973 and 1993.
- Images of areas < or equal to 1 km (value of 2) and > 1 km (value of 1), from waterpoints in the dry season were created for 1973 and 1993.
- Additional preference image was created of riverine vegetation which was identified as areas with 50m of main rivers. 50m was considered to be appropriate in Kanyati as riverine vegetation is found on the narrow, steep slopes bordering rivers.

4.3.4c Elephant

- Images of suitable land cover were identified as all woodland categories with the exclusion of cultivated, grazed/cleared and settled land, for 1973 and 1993.

- Images of < or equal to 20 km (value of 2) and > 20km (value of 1), from waterpoints in the dry season were created for 1973 and 1993 and covered the whole area for each year. In other words the whole area had water accessible to elephants.

4.3.4d Kudu

- Images of suitable land cover were identified as all woodland categories with the exclusion of cultivated, grazed/cleared and settled land, for 1973 and 1993.
- Images of < or equal to 10 km (value of 2) and > 10km (value of 1), from waterpoints in the dry season were created for 1973 and 1993.

4.3.4e Sable

- Images of suitable land cover were identified as all woodland categories with the exclusion of cultivated, grazed/cleared and settled land, for 1973 and 1993.
- Images of < or equal to 5 km (value of 2) and > 5 km (value of 1), from waterpoints in the dry season were created for 1973 and 1993.
- Additional preference images of open woodland with termitaria type B were created for 1973 and 1993.

4.3.4f Waterbuck

- Images of suitable land cover were identified as all woodland categories with the exclusion of cultivated, grazed/cleared and settled land, for 1973 and 1993.

- Images of < or equal to 5 km (value of 2) and > 5 km (value of 1), from waterpoints in the dry season were created for 1973 and 1993.
- Additional preference images of 1 km from waterpoints in 1973 and 1993 were created for 1973 and 1993.

4.3.4g Zebra

- Images of suitable land cover were identified as all woodland categories with the exclusion of cultivated, grazed/cleared and settled land, for 1973 and 1993.
- Images of < or equal to 10 km (value of 2) and > 10km (value of 1), from waterpoints in the dry season were created for 1973 and 1993.
- Additional preference images of open woodland with termitaria type B were created for 1973 and 1993.

Further analysis of the habitat suitability maps and the sizes of areas of suitable habitat occurred, with a focus on their distribution from the game fence into the settled area. This was to obtain an indication of whether the patches of suitable habitat within the settled area were accessible or not. Areas of a specific size and larger were selected for species with small home ranges such as bushbuck, sable and waterbuck. Areas of 1 or 5 km^2 were selected for those species with large home ranges, but which travel larger distances to find food and water.

4.3.5. Other software options for measurement of spatial pattern

- ATLAS-GIS: Used for initial data capture and disaggregation of polygon layers/themes. Limited to vector format only, with limiting analytical functions. For example ArcView 3.0 allows for summary statistics of all attributes to be calculated and proximity analyses using raster data.
- IDRISI: The spatial pattern measures in IDRISI were not appropriate as they are calculated for the whole landscape, not specific land cover types or patches. They included simple relative richness, diversity, dominance and fragmentation indices and some neighbourhood analysis operators. These would be more useful if there were more than one landscape/study site and more land cover types.
- FRAGSTATS: This is a spatial pattern analysis programme for quantifying landscape structure, developed by the US Dept. of Agriculture Forest Service (McGarigal & Marks, 1995). It allows automated analysis using many landscape metrics using vector or raster images. Unfortunately attempts to operate it using IDRISI image files were unsuccessful as were attempts to locate the programmer of this module. Vector files could only be used in a workstation ArcInfo environment that was not readily available. It was decided that the program should not be used as the only means of analysis and only the landscape metrics applicable to this study were selected. It is important to understand the exact meaning of each metric before use, as was stressed by the authors.

5. RESULTS

Results of analyses using methods detailed in the previous chapter are presented below. The patterns of land cover change over the twenty-year period from 1973 to 1993, such as which land cover types were fragmented, are in the first section. The results of analyses using different extents (those of the wildlife and the settled area separately) compared with land cover change in the whole area, are in the second section. The spatial distribution of land cover types with slope and proximity to rivers is in the next two sections. Habitat suitability analyses and maps are found in the last section.

5.1 Land cover change patterns

Seven different land cover types were identified (Table 1 and Fig. 3 - 6): cultivation, settlement, grazed/cleared, miombo woodland, woodland with termitaria A, open woodland and woodland with cleared termitaria, comprising 621km^2 in total. The miombo woodland comprised the most extensive land cover type with largest contiguous areas, dominating the landscape and could therefore also be described as the 'matrix'. The miombo woodland and the termitaria woodland pattern A (WDTa), were fragmented during the period 1973 - 1993, as the number of spatial entities/patches increased dramatically and the areal extent decreased. This is significant as miombo and termitaria woodland constituted the majority of miombo woodland in the area. Open woodland (WDTb) and woodland with cleared termitaria (WDTc) occupied much smaller proportions of the whole area (Fig.7).

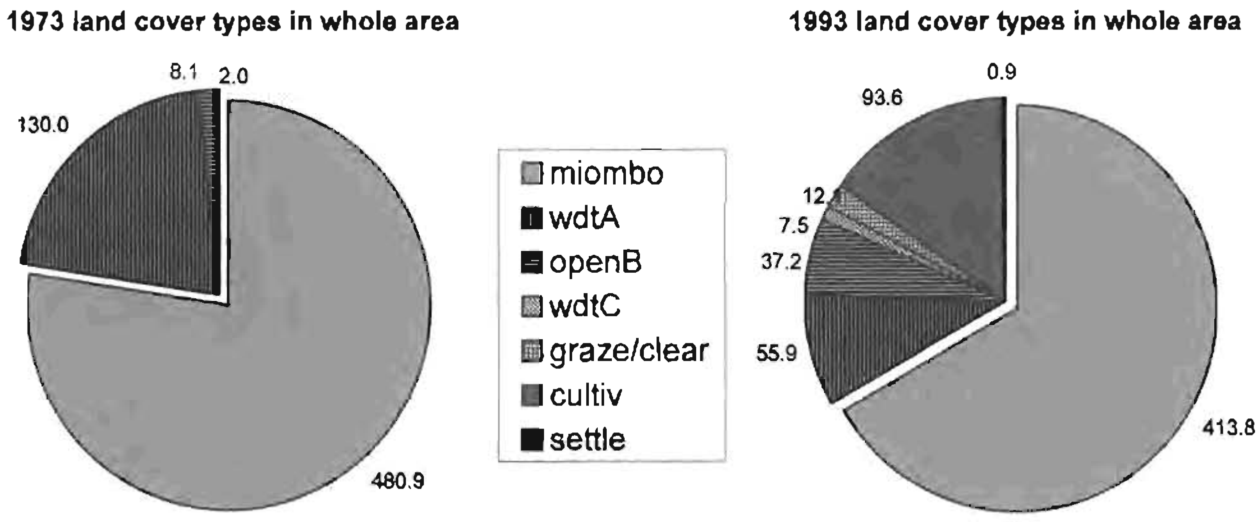

Fig. 7 Areas (km2) of each land cover type, with proportions of whole area indicated by pie chart slices

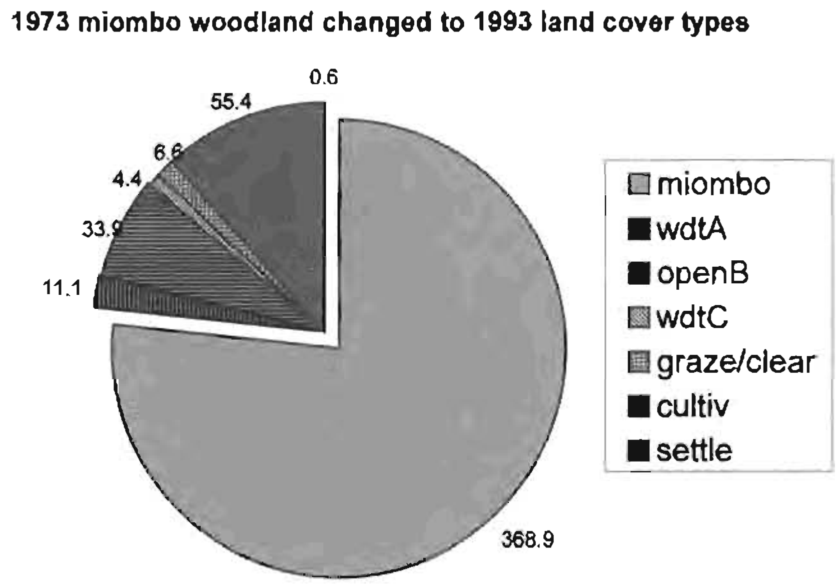

Fig. 8 Areas (km2) of 1973 miombo woodland which changed to 1993 land cover types, with proportions indicated by pie chart slices

The average size of the spatial elements/patches in the woodland with termitaria pattern A decreased by 75% and 95% for the miombo woodland by 1993. The termitaria woodland pattern A increased from 23 in 1973 to 42 spatial elements in1993, and for the miombo woodland, from 3 to 52 spatial features. Miombo woodland and woodland with termitaria pattern A were fragmented and substituted by cultivation, grazed/cleared land, open woodland with termitaria pattern B, and to a lesser extent by woodland with cleared termitaria and settlement. Table 6 shows the spatial measures of all the land cover types. The net decrease in the amount of miombo woodland was 13.9% (67.3 km^2). This includes areas, which were termitaria woodland type A and B in 1973, which changed to miombo woodland in 1993 (augmenting the area of miombo woodland in 1993). The percentages of the miombo woodland in 1973 converted to land cover types in 1993 are shown in Fig.8. A significant proportion of termitaria woodland type A in 1973 was changed to miombo woodland (without termitaria) in 1993, indicating that the termitaria vegetation were removed from these areas during the twenty-year period. Approximately the same amount of land (40 km^2) was converted from termitaria woodland type A to cultivated and grazed/cleared land. A small proportion was converted to termitaria woodland type B. These patterns of change of termitaria woodland type A converted to other land cover types in 1993, are shown in Fig. 9.

Table 6 Spatial measures of land cover types in Kanyati

year	land cover	No. of spatial elements [10]	Area (km^2)	Minimum area	Maximum area	Average area	Standard deviation of area	Minimum Fractal Dimension [11]	Maximum Fractal Dimension	Average Fractal Dimension
1973	Miombo woodland	3	480.95	1.917775	470.04	160.3523	268.22	1.22	1.29	1.25
1993	Miombo woodland	52	413.77	0.000075	409.51	7.9708	56.78	1.21	1.96	1.40
1973	Woodland with termitaria pattern A	23	130.03	0.059568	91.69	5.6552	18.91	1.20	1.32	1.25
1993	Woodland with termitaria pattern A	42	55.92	0.007026	11.29	1.4224	2.70	1.21	1.38	1.30
1973	Open woodland with termitaria pattern B	10	8.09	0.061172	3.56	0.8099	1.15	1.22	1.34	1.28
1993	Open woodland with termitaria pattern B	82	37.24	0.003240	3.99	0.4785	0.72	1.21	1.42	1.30
1973	Woodland with cleared termitaria	1	1.97	1.947921	1.97	1.9749	0.00	1.20	1.20	1.20
1993	Woodland with cleared termitaria	6	7.46	0.046002	3.42	1.2431	1.39	1.25	1.29	1.26
1973	Settlement	1	0.00	0.0017	0.0017	0.0017	0.00	1.35	1.35	1.35
1993	Settlement	606	0.90	0.000035	0.04	0.0015	0.00	1.26	1.92	1.39
1993	Cultivation	417	93.67	0.002601	4.58	0.2246	0.51	1.23	1.41	1.30
1993	Grazed/cleared	100	12.14	0.004493	1.47	0.1218	0.20	1.25	1.42	1.31
1973	*Tracks* [12]	*33*	*149.53*	*0.000758*	*18.10*	*4.5312*	*4.52*	*n/a*	*n/a*	*n/a*
1993	*Tracks*	*196*	*461.25*	*0.009264*	*27.21*	*2.3533*	*3.87*	*n/a*	*n/a*	*n/a*

10 Spatial elements refer to the separate geographic features within each land cover type: polygons or patches or lines in the case of tracks.

11 Fractal Dimension calculated for each polygon using the formula: 2 * (ln[Perimeter]/ln[Area])

12 Measures of tracks which are line features, are total lengths in kilometres not kilometres squared. The fractal dimension could not be calculated because of this aspect (need perimeter and area measures).

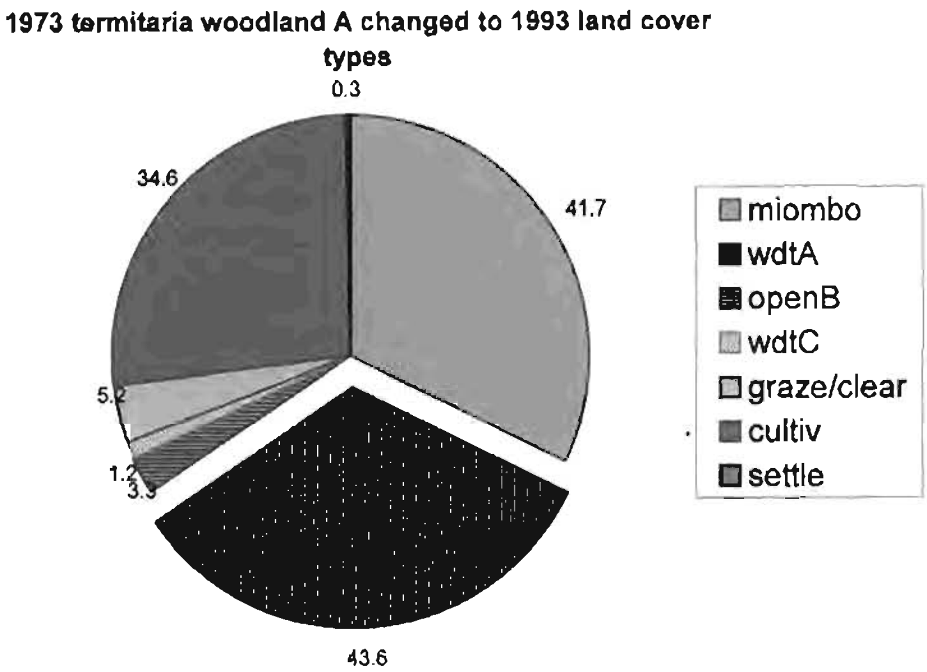

Fig.9 Areas (km2) of 1973 termitaria woodland which changed to 1993 land cover types, with proportions indicated by pie chart slices

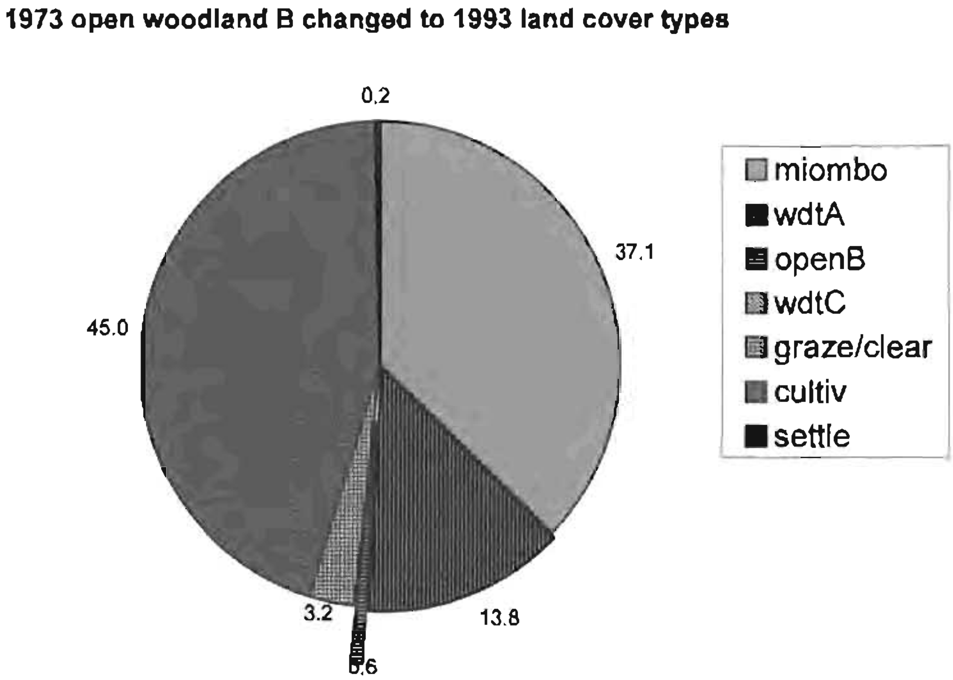

Fig.10 Areas (km2) of 1973 open woodland which changed to 1993 land cover types, with proportions indicated by pie chart slices

The open woodland with termitaria type B increased in areal extent by 384%, with a similarly dramatic increase in the number of patches (Table 6). There was very little spatial correlation between the areas identified as termitaria woodland type B in 1973 and 1993, as a very small percentage remained the same. Almost half was converted to cultivation and grazed/cleared land in 1993, with a slightly smaller amount to miombo woodland and smaller proportion to termitaria woodland type A. These patterns (Fig. 10) indicate that this land cover type was significantly transformed into other land cover types, and possibly may represent some misclassification. Analysis of the spatial distribution of termitaria woodland type B in 1993 and what the same areas were identified as in 1973, shows that the vast majority was miombo woodland with a small proportion being termitaria woodland A and only 0.14% unchanged. This is shown in Figure 11. Further analysis of the distribution of this land cover type in relation to the wildlife and settled areas is discussed in the section 5.2. The total amount of tracks quadrupled from 1973 to 1993 facilitating expansion of cultivation and settled areas within Kanyati. The areal extent and number of spatial features of woodland with cleared termitaria increased over the twenty-year period. The area in 1973 remained mostly the same (92%) in 1993, with miombo woodland and termitaria woodland type A being converted to woodland with cleared termitaria in 1993, as shown in Fig. 12. This would have been due to the removal of termitaria vegetation by fire and/or herbivores, probably elephant. By 1993 the amount of cultivated, grazed/cleared and settled land had increased from none at all in 1973 (Table 6 and Fig. 7). The total area occupied by settlement appears small for the 606 spatial features that it comprises, but this is the actual land occupied by small huts and outhouses as shown by the minimum spatial feature size (1 500m^2 in 1993). Cultivated and grazed/cleared land was previously miombo woodland (majority), termitaria woodland type A and type B as shown in Fig. 13

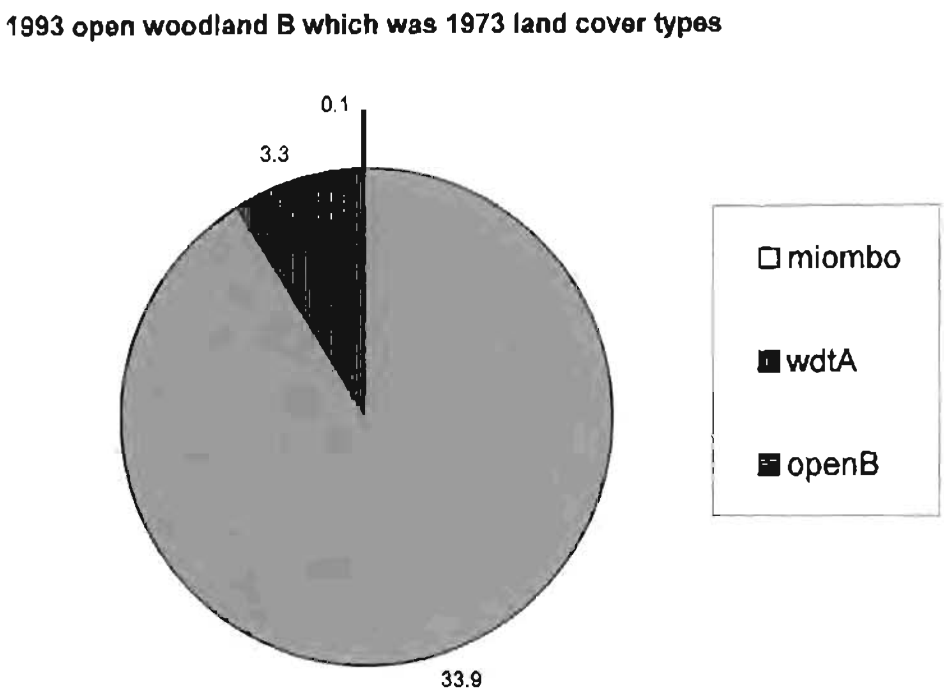

Fig.11 Areas (km2) of 1993 open woodland which changed from 1973 land cover types, with proportions indicated by pie chart slices

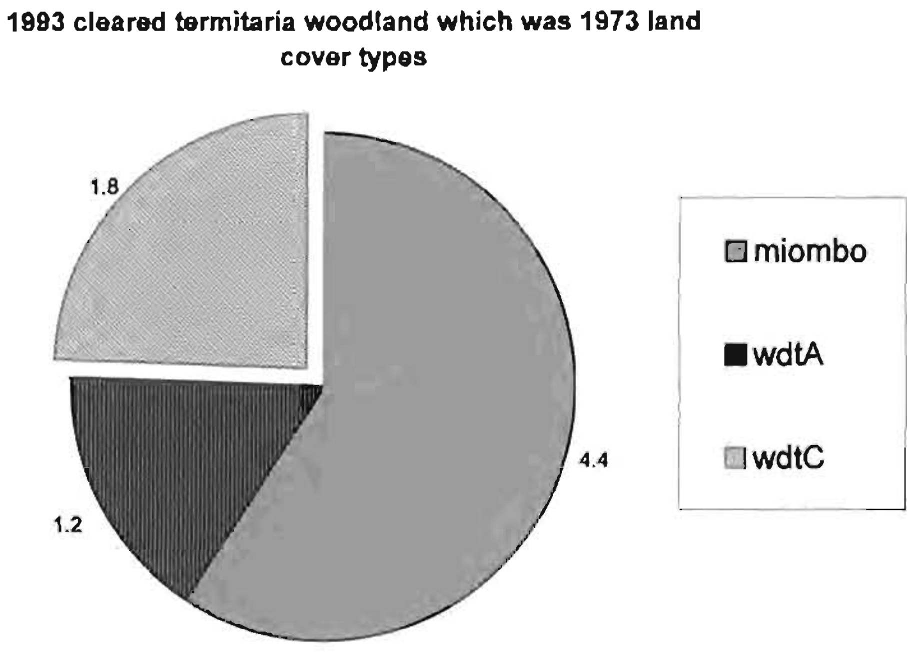

Fig.12 Areas (km2) of 1993 cleared termitaria woodland which changed from 1973 landcover types, with proportions indicated by pie chart slices

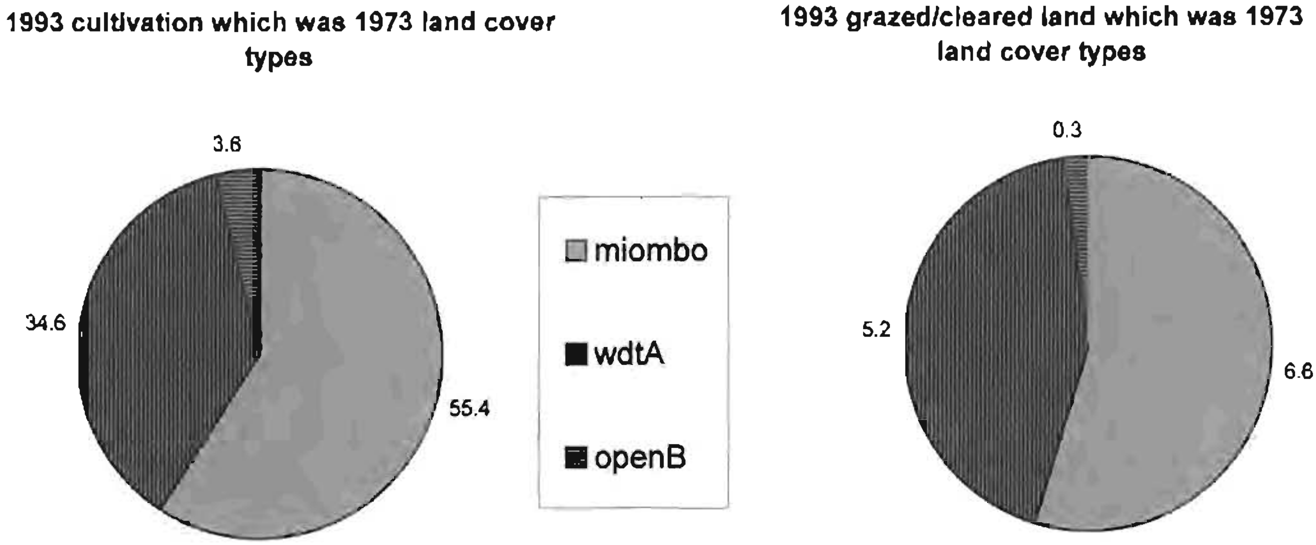

Fig.13 Areas (km2) of 1993 cultivation & grazed/cleared land which changed from 1973 landcover types, with proportions indicated by pie chart slices

The average fractal dimension values of the land cover types in 1973 all increased by 1993 (Wilcoxon signed rank test, Z value of -5.373, $P< 0.001$; Friedman test $\chi^2 = 38$, $P< 0.001$). The fractal dimension and the change in fractal dimension (Fig.14) indicated fragmentation with more edge/perimeter per area of spatial elements. The minimum fractal dimensions remained relatively constant for all land cover types during the twenty-year period. The cultivated, grazed/cleared and settled land cover types had higher minimum values than the other land cover types except for the settled areas. There was only one spatial feature for settlement in 1973, which had the highest minimum value, which decreased in the average minimum values for settlement in 1993. The extremely high maximum values for the 1993 miombo woodland and 1993 settlement are from polygons with some of the smallest areas and perimeters of all the land cover types. These polygons have very angular, 'spikey' shapes (in some cases almost triangular) as opposed to ones with rounded shapes with lower fractal dimensions. In the case of the miombo woodland these polygons were fragments bordered by cultivated or grazed/cleared land and termitaria woodland types and were essentially outliers. The maximum value of miombo woodland excluding these outliers was 1.6. The spatial features with the largest area of all the land cover types in 1993, from the miombo woodland had a fractal dimension of 1.43 which was still higher than the average of the other land cover types. The spatial distribution of the fractal dimensions for the two years are shown in Figure 15.

Hulshoff's shape indices (see Section 2.5.3) were also calculated for each land cover type. S1 measures the mean perimeter to area ratio where a relatively high value represents many patches with small interiors. S2 measures the deviation from a circular or square patch with the same

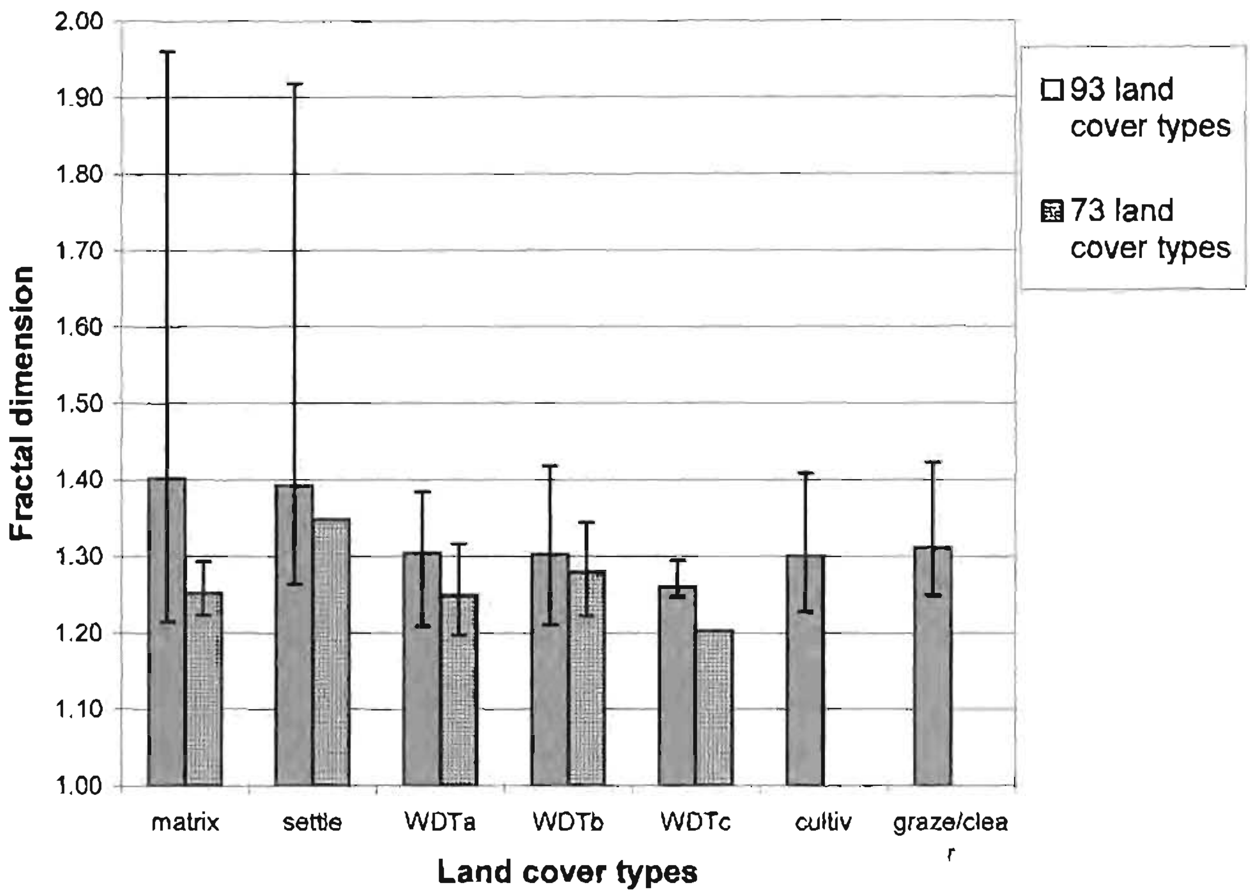

Fig.14 Average fractal dimensions of land cover types (bars) with minimum and maximum values shown

area, essentially measuring complexity of shape as compared with isodiametric shapes, which contain the most patch interior. The values are shown in Table 7 below. The lowest values of S1 indicate many spatial elements or patches with relatively large interiors such as 1973 miombo woodland, cleared termitaria woodland (both years) and termitaria woodland type A in 1973. The settled areas had some of the highest values of S1 as well as 1993 miombo woodland, indicating many spatial elements with relatively small interiors. S1 increased for every land cover type during the twenty-year period indicating smaller spatial elements. The inverse pattern was evident with S2, as the lowest values were attributable to settled areas describing very little deviation from simple, isodiametric shapes such as the circle. Cleared termitaria cultivated and grazed/cleared land also had relatively low values for S2. Termitaria woodland type A in 1973 and type B in both years showed slightly higher values, with the miombo woodland and termitaria woodland type A in 1993 having the highest values.

Table 7 Hulshoff's shape indices for each land cover type per year

YEAR	LAND COVER	No. of spatial entities	S1	S2
1993	cultivated	418	0.0232	1.5964
1993	graze/clear	100	0.0246	1.6166
1973	miombo woodland	3	0.0022	2.8623
1993	miombo woodland	52	0.1243	2.1287
1973	settle	1	0.0882	1.028
1993	settle	606	0.1262	1.0965
1973	WDTa	23	0.0069	1.6426
1993	WDTa	42	0.0155	2.1536
1973	WDTb	10	0.0117	1.7226
1993	WDTb	82	0.0173	1.8565
1973	WDTc	1	0.0031	1.2207
1993	WDTc	6	0.0101	1.5395

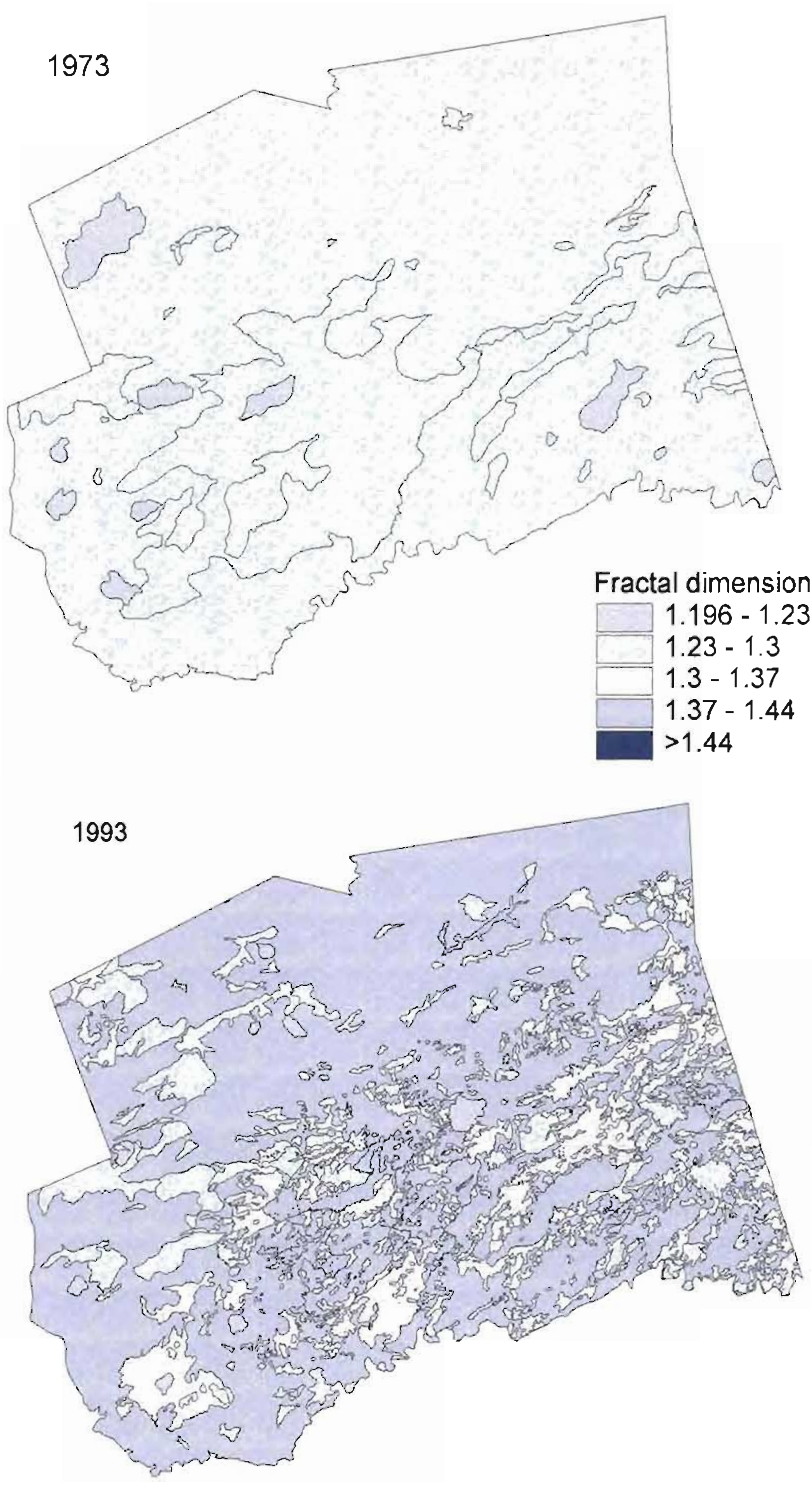

Fig. 15 The distribution of fractal dimensions in land cover types in Kanyati

All land cover types except the miombo woodland showed increases in S2 during the twenty-year period, meaning that the shapes of the spatial elements were becoming increasingly complex, in differing amounts. The simplest shapes (most closely approximating a circle or a square) approach the maximum patch interior so in 1993, higher values of S2 indicate less interior area.

5.2 Change in extent: analyses of the wildlife and settled areas

A change in the extent of analysis by analysing the wildlife and settled areas separately showed different patterns in comparison to the larger extent of the whole study area. The wildlife area comprises 334.48 km^2 and the settled area, 286.24 km^2. The proportion of the wildlife area as miombo woodland was higher in comparison to the whole area and the settled area in 1973 and 1993. A higher percentage of woodland, both miombo woodland and termitaria woodland A, was converted to other land cover types in the settled area than in the wildlife area. Related to this were the much higher percentages of land occupied by cultivation, grazed/cleared land and settled land in the settled area compared with the whole area and wildlife area. The percentages were almost double that of the whole area and more than ten times those in the wildlife area with one exception. The percentage of grazed/cleared land in the settled area was only four times more than that of the wildlife area as opposed to the much higher differences mentioned previously. Cultivation still occurred in the wildlife area (8.15 km sq. of miombo woodland in 1973 was converted to cultivated land in the wildlife area in 1993) in spite of not being permitted.

The proportion of termitaria woodland type B was highest in the wildlife area in 1993 from none in 1973. The proportions stayed the same in the settled area at approximately 3%. Woodland with cleared termitaria was only found in the wildlife area in 1973 and 1993.

A change in extent therefore shows significant differences in the extent of habitat fragmentation. Figure 16 shows the different percentages of land cover types in each area for both time periods. Analysis of the miombo woodland and its conversion to different land cover types in some areas in 1993 is shown in Table 8. The settled area showed a lower percentage staying intact, with corresponding higher percentages converted to cultivation and grazed/cleared land. The majority of miombo woodland converted to termitaria woodland type B and cleared termitaria woodland, was in the wildlife area.

Table 8 Percentages of 1973 miombo woodland which changed to 1993 land cover types, with varying extents

% changed	Miombo	Cultivated	Graze /clear	Settle	WDTa	WDTb	WDTc	Total
whole	76.71	11.51	1.58	0.11	2.31	7.05	0.92	100
settled	64.99	25.78	3.07	0.26	1.46	4.44	0.00	100
wildlife	85.52	0.76	0.11	0.00	2.92	9.07	1.61	100

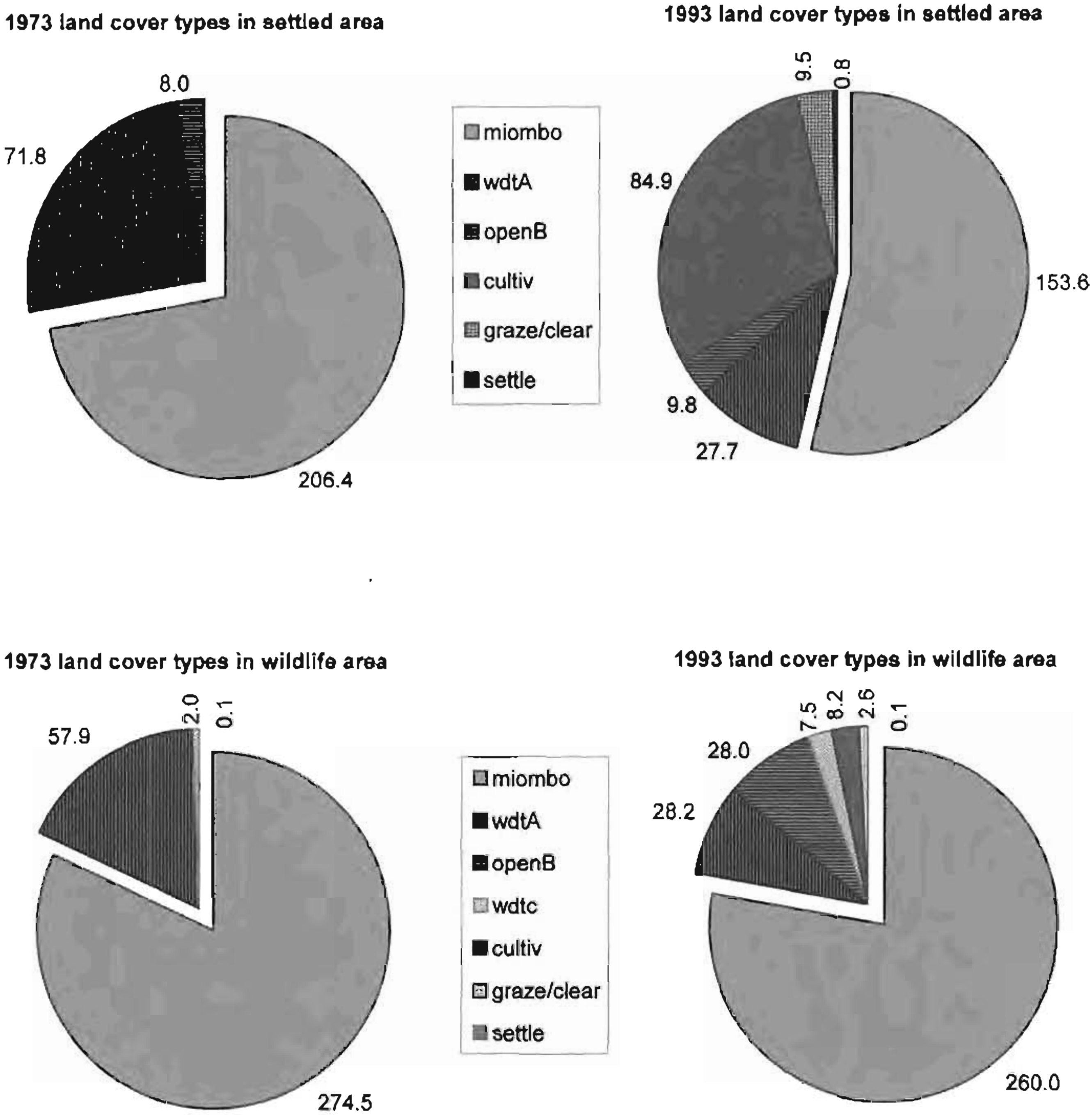

Fig. 16 Comparison of areas (km2) of land cover types in the wildlife and settled areas, with proportions indicated by pie chart slices

5.3 Distribution of land cover types with slope

The areas occupied by each of the slope classes (degrees of slope) are shown in a cumulative frequency graph in Figure 17. The majority of the land cover types were found in the lowest two slope classes which comprise 0 – 8 degrees, with a dramatic decrease in amounts of land in higher slope classes. This was a general trend shared by all land cover types in 1973 and 1993 as shown by Figures 18 and 19. The most extensive land cover type, the miombo woodland, did not show as steep a decline in area with increase in slope as the other land cover types. A slight deviation from this downward trend was found (in 1973 and 1993) at slope class 16 – 25 degrees with an increase in area of miombo woodland before decreasing again. This was probably due to the larger width of this class compared with the previous class. The percentages of miombo woodland within each slope class are shown in Fig. 20.

Woodland with termitaria pattern B differed in distribution with slope from 1973 to 1993. A larger proportion was in slope class 0 – 4 (flat land) in 1973 than in 1993, when the proportion was halved. Higher proportions of this land cover type were found in higher slope classes in 1993 as shown in Fig. 21.

The vast majority of cultivated land, grazed/cleared land and settled land were found within the 0 - 8 slope classes, which is relatively flat land. The maximum slope class that cultivation and grazed/cleared land were found within was 25-35 degrees, but only very small areas. The maximum slope class that settlement was found within is 16-25 degrees of slope. (The maximum value of slope overall in the study area was 75.14/). Figure 22 shows the percentages of cultivated, grazed/cleared and settled land in 1993, in each slope class.

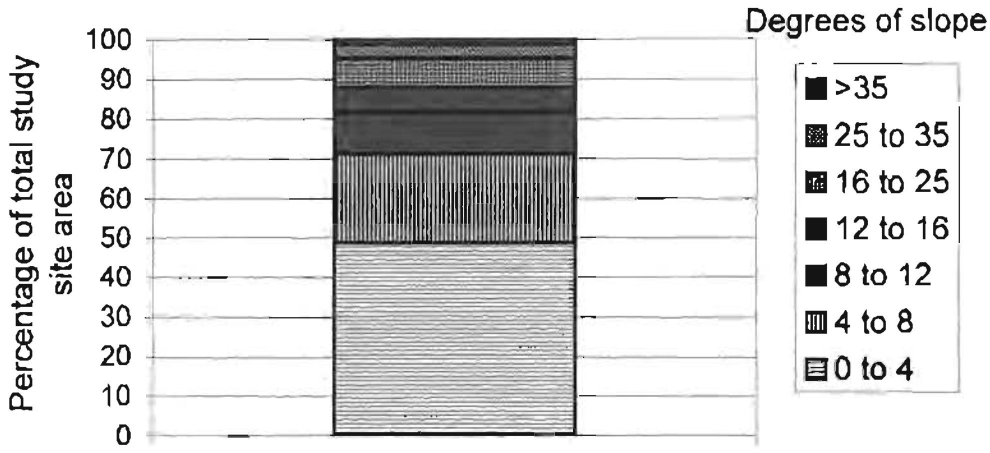

Fig. 17 Percentage of whole area occupied by each class

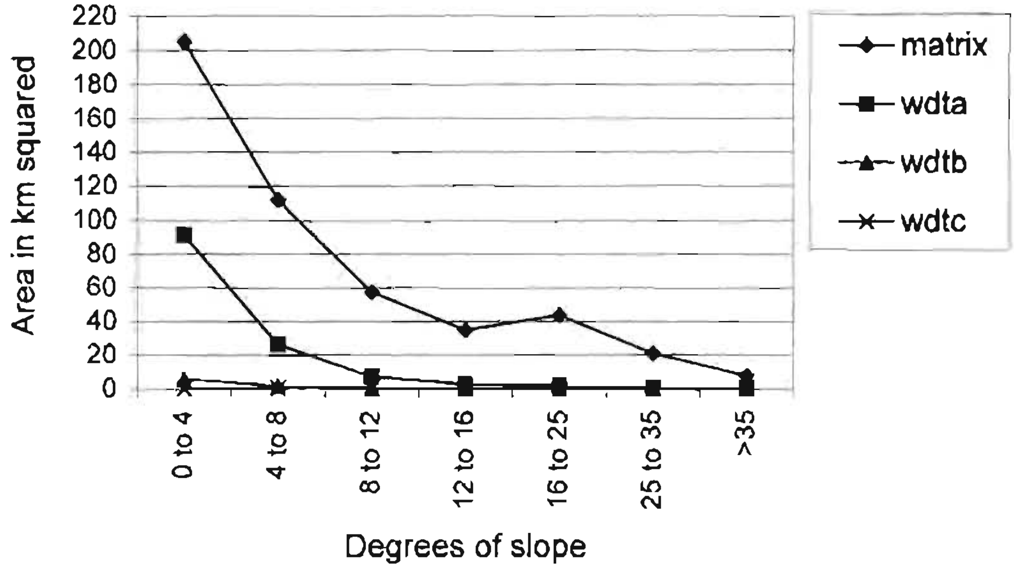

Fig. 18 Areas (km2) of 1973 land cover types within each slope class

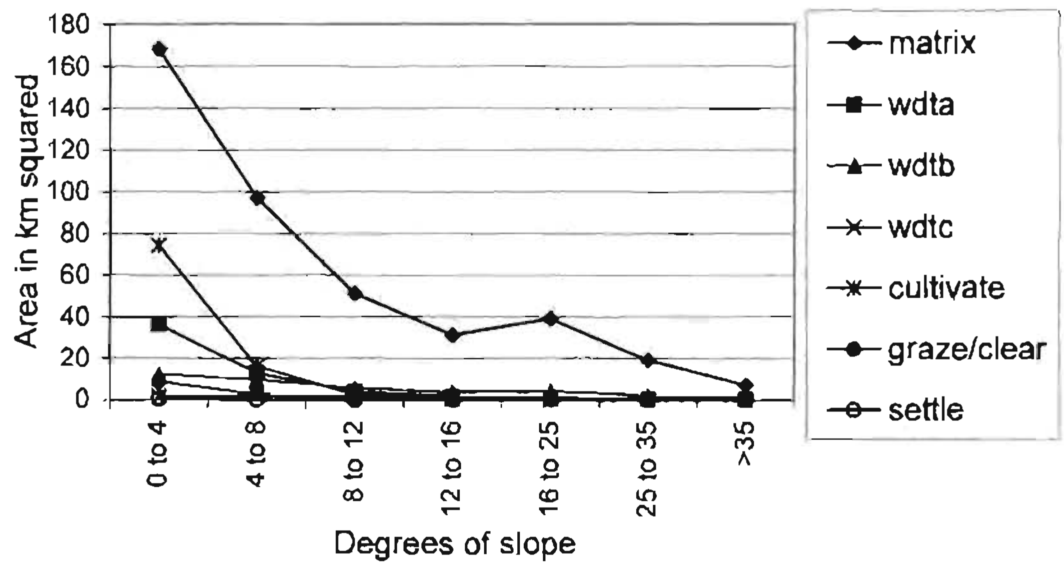

Fig. 19 Areas (km2) of 1993 land cover types within each slope class

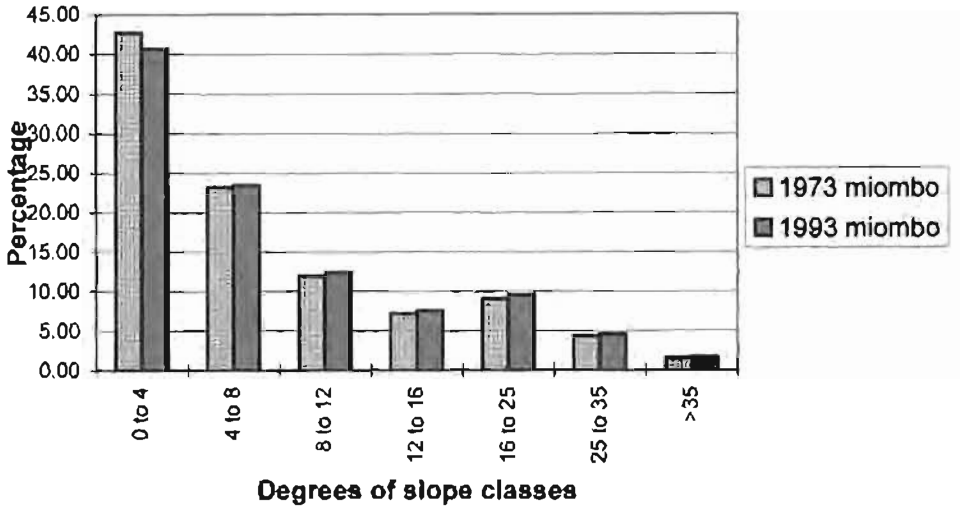

Fig. 20 Percentage of miombo woodland in each slope class for both years

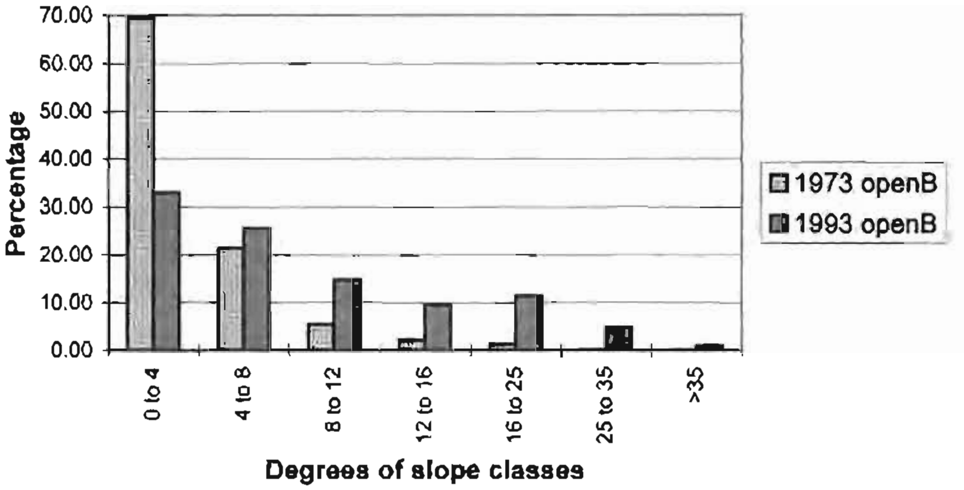

Fig. 21 Percentage of open woodland with termitaria in each slope class for both years

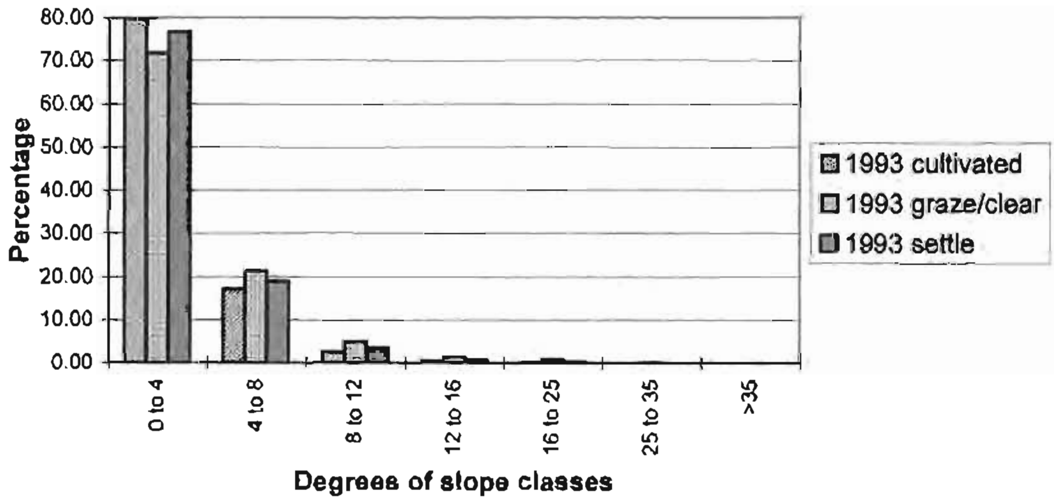

Fig. 22 Percentage of cultivated, grazed/cleared and settled land in each slope class for both years

The percentage of the settled and wildlife areas per slope class area shows different patterns. A higher percentage of the wildlife area comprises higher slope classes compared to the settled area and the entire area. 70% of the wildlife area is more than 4 degrees of slope compared to almost 70% of the settled area being 0 - 4 degrees of slope (Fig. 23). Analysis of the distribution of land cover types with slope with a decrease in extent i.e. wildlife and settled areas, showed similar general patterns for the settled area for both years. The wildlife area showed a slightly different distribution of miombo woodland amongst slope classes. There was a more gradual decrease in the distribution of miombo woodland with increased slope as shown in Fig. 24.

5.4 Proximity of land cover types to rivers

The percentages of the whole area occupied by each river buffers are shown in Fig. 25. The majority of land in Kanyati is within 1 km of a first or second order river. These may include some seasonal rivers, as this was not denoted on the topographic maps from which the data was digitized. Analysis of proximity of rivers to land cover types show that the majority of each land cover type is found within 1 km of rivers, with decreasing amounts with distance from rivers (see Fig.26 and 27). One exception was cleared termitaria land, which was primarily found 5 km from rivers, all in 1973 with less in 1993, as more areas were found closer to rivers. There were other changes of the distributions from 1973 - 1993. Termitaria woodland type A had more areas closer to rivers in 1993 and termitaria woodland type B had fewer areas closer to rivers. There was only one area of settled land in 1973 and it was all found within 1 km of rivers with more areas further away in 1993. Cultivated land was mostly found within 1 - 2 km of rivers as with grazed/cleared land although about 24% of this land cover was found within 5 km.

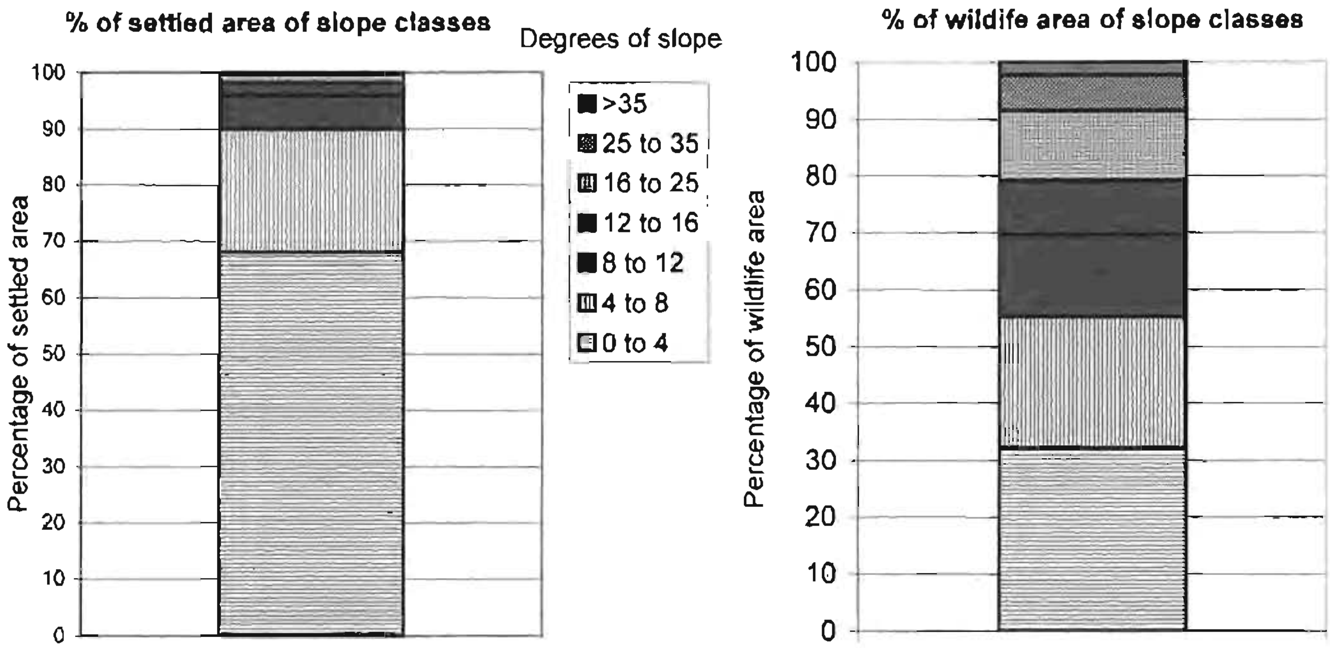

Fig.23 Percentages of settled and wildlife areas in each slope class

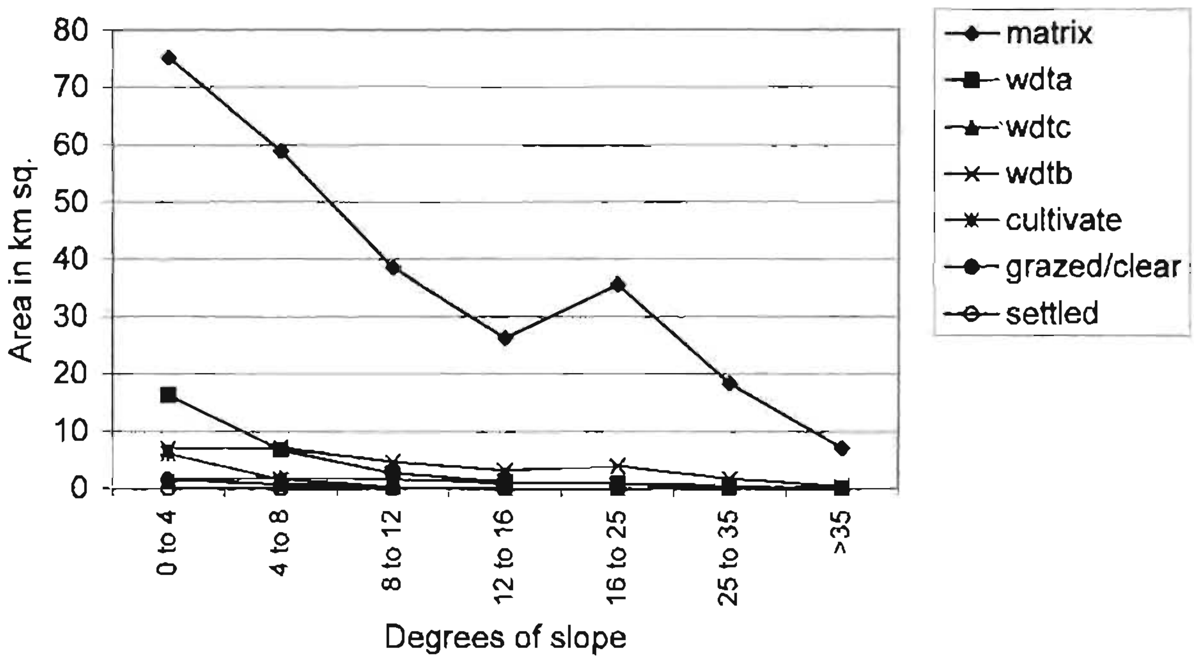

Fig.24 Areas (km2) of 1993 land cover types in wildlife area within each slope class

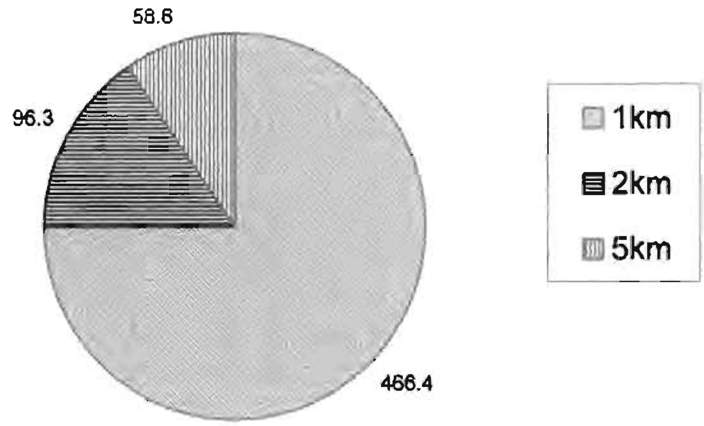

Fig.25 Area (km2) occupied by each river buffer, with proportions of whole area indicated by pie slices

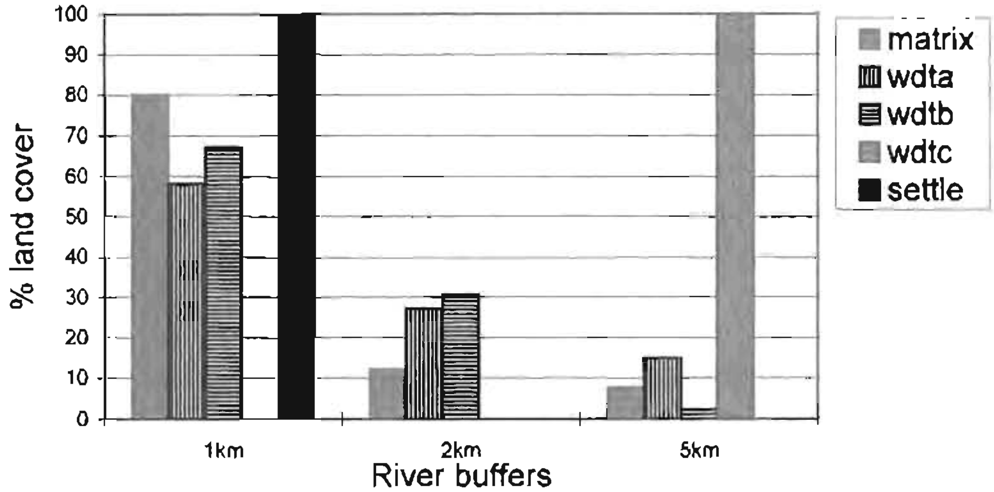

Fig.26 Percentage of 1973 land cover types with distance from rivers

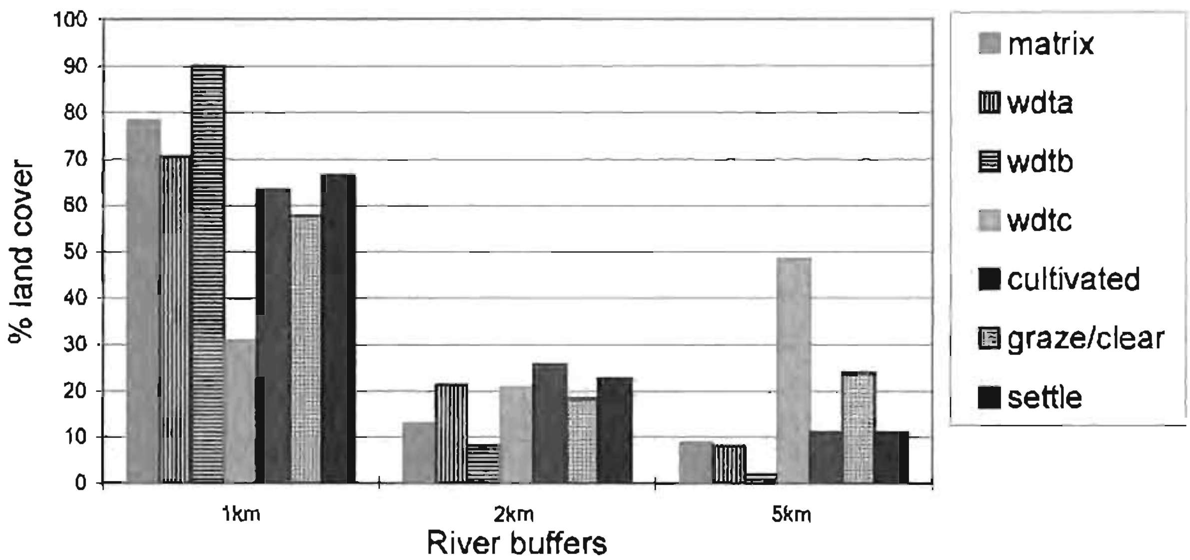

Fig.26 Percentage of 1993 land cover types with distance from rivers

5.5 **Ecological significance of habitat fragmentation on key species**

The likely ecological effects of habitat fragmentation and substitution on key species in the area, was shown in habitat suitability maps for 1973 and 1993 for the whole area. The key species were: buffalo, bushbuck, elephant, kudu, sable, waterbuck and zebra. The classes of habitat suitability were as follows:

0 = inaccessible (> 60 degrees slope and areas of cultivation, grazed/cleared or settled land)

1 = unsuitable

2 = moderately unsuitable

3 = not preferable

4 = used, not preferable

5 = suitable

6 = preferable

7 = highly preferable

The habitat suitability maps (Figures 28 -34) show the patterns of habitat change from 1973 to 1993. A maximum of seven classes of suitability (with values of 0 to 7) resulted from the image overlays, with some species (such as elephant and kudu) having a maximum value of 6. This was the case when no additional preferences images were added to these habitat suitability maps. Values of 0 to 3 were generally those classes with inaccessible or unsuitable land (in the case of very high slopes or cultivated land) or land that would be used (possibly simply for passing through) but not preferred as habitat. Values of 4 to 7 represent more suitable habitat with the higher values being more preferred habitat. Patterns of fragmentation of suitable habitat by unsuitable areas, such as cultivation, are clearly shown in the 1993 maps. The settled area showed a marked increase in inaccessible or unsuitable areas for all species (shown in red). Buffalo, elephant, kudu and zebra showed decreases in the amount of suitable habitat areas from 1973 to 1993. Waterbuck, sable and bushbuck did not show changes in 1993, i.e. the amount of suitable and unsuitable land that remained approximately the same. Any increases in unsuitable land in 1993 in the settled area, from cultivated, grazed/cleared and settled land were probably offset by more areas becoming accessible or more suitable, through increased availability of waterpoints for these species. This does not necessarily mean that animals would definitely venture to these waterpoints, as this would depend on how intense the settlement around these areas is and how affected each species would be by the presence of people. The total areas of suitable and unsuitable land for each species and year are shown in Table 10.

The section of suitable habitat with the largest area for most species decreased in size by 1993 and became more perforated and fragmented by unsuitable areas. These relatively contiguous large areas were situated in the southern part of Kanyati, stretching from the wildlife area across the settled area. In the case of bushbuck, the largest contiguous area of suitable habitat in 1973 was broken into several smaller, non-adjacent, unsuitable areas by 1993, as opposed to a reduction in size. The largest contiguous areas found in the wildlife area comprise the most likely part of Kanyati to be utilised by large mammalian herbivores, especially those species that shy away from settled areas, such as buffalo. Analysis of suitable areas in the settled area with distance from the game fence occurred with the rationale that animals may venture into the settled area for food, but would primarily inhabit the wildlife area, especially those with large home ranges (buffalo, elephant and zebra). The game fence is meant to prevent movement of large mammals, especially buffalo between the two areas for purposes of disease control. This is seldom an effective barrier, as areas along the fence have gaps to allow cattle to graze in the wildlife area and some species especially kudu and elephant can cross the fence.

The habitat suitability maps show some areas which have similar values throughout the species, such as in the north-western corner of Kanyati. This is because these areas are all within vicinity of water and are within the same habitat, miombo woodland or termitaria woodland which was considered to be suitable for all species.

Table 9 Total areas (km^2) of suitable and unsuitable habitat for key species

Year	*Species*	*Unsuitable areas (values 0 -3)*	*Suitable areas (values 4 - 7)*
1973	buffalo	49.34	571.76
1993	buffalo	122.16	498.88
1973	bushbuck	558.35	63.17
1993	bushbuck	554.30	66.74
1973	elephant	15.50	606.02
1993	elephant	122.16	498.88
1973	kudu	49.62	571.91
1993	kudu	122.16	498.88
1973	sable	223.02	398.08
1993	sable	222.66	398.38
1973	waterbuck	228.37	393.15
1993	waterbuck	226.66	394.39
1973	zebra	49.34	571.76
1993	zebra	122.16	498.88

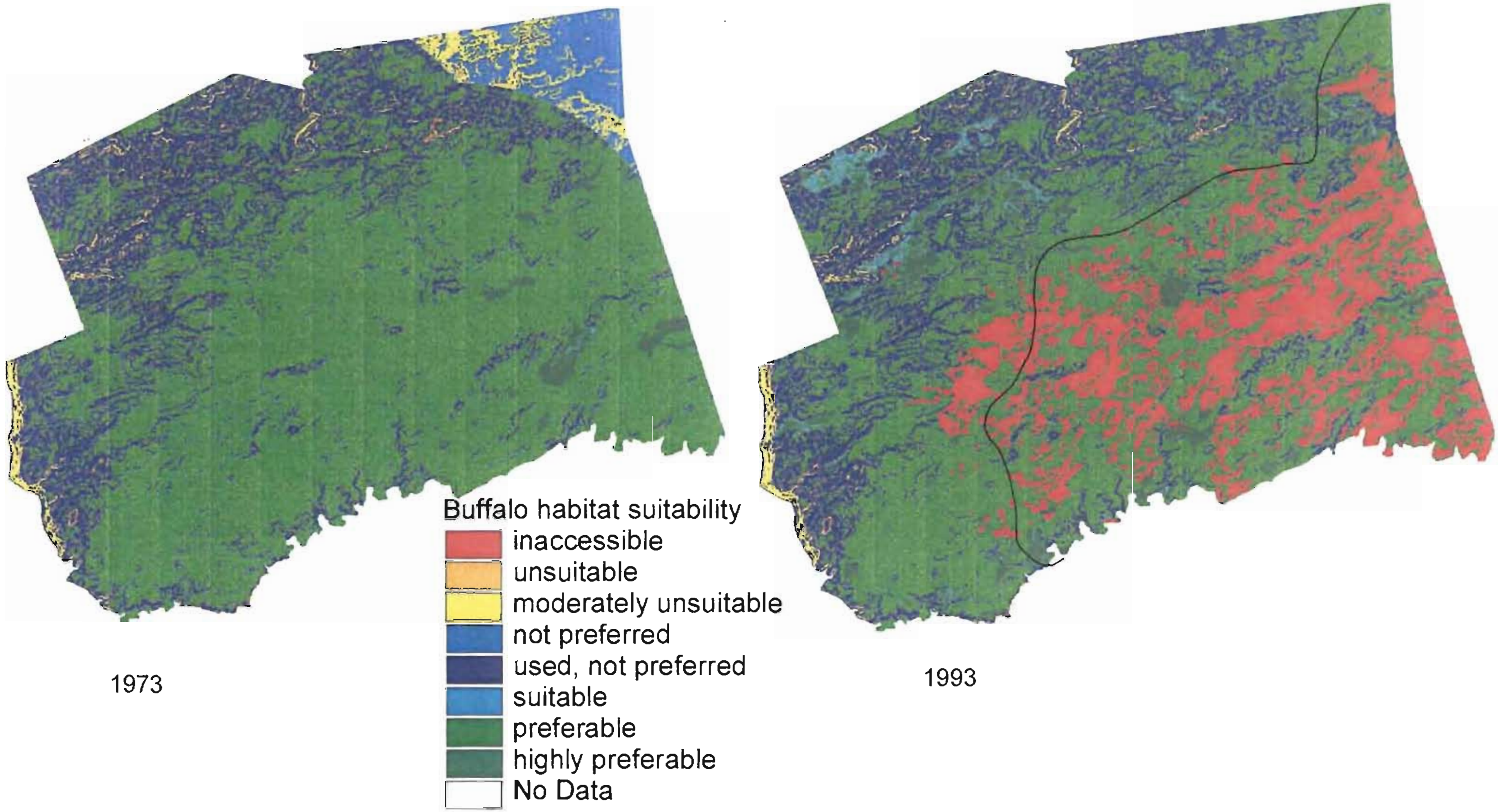

Fig. 28 Habitat suitability maps for buffalo in 1973 and 1993 in Kanyati

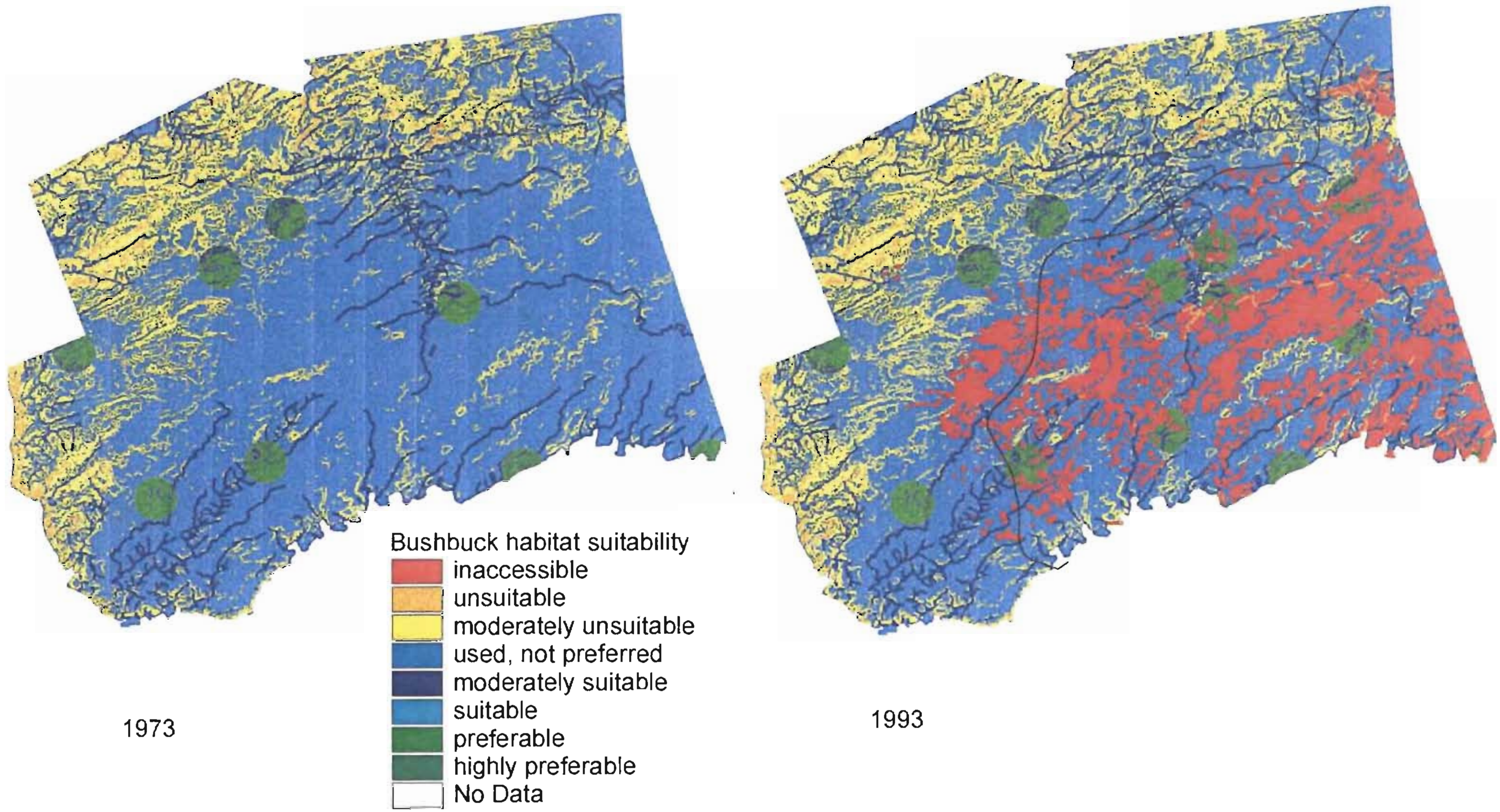

Fig. 29 Habitat suitability maps for bushbuck in 1973 and 1993 in Kanyati

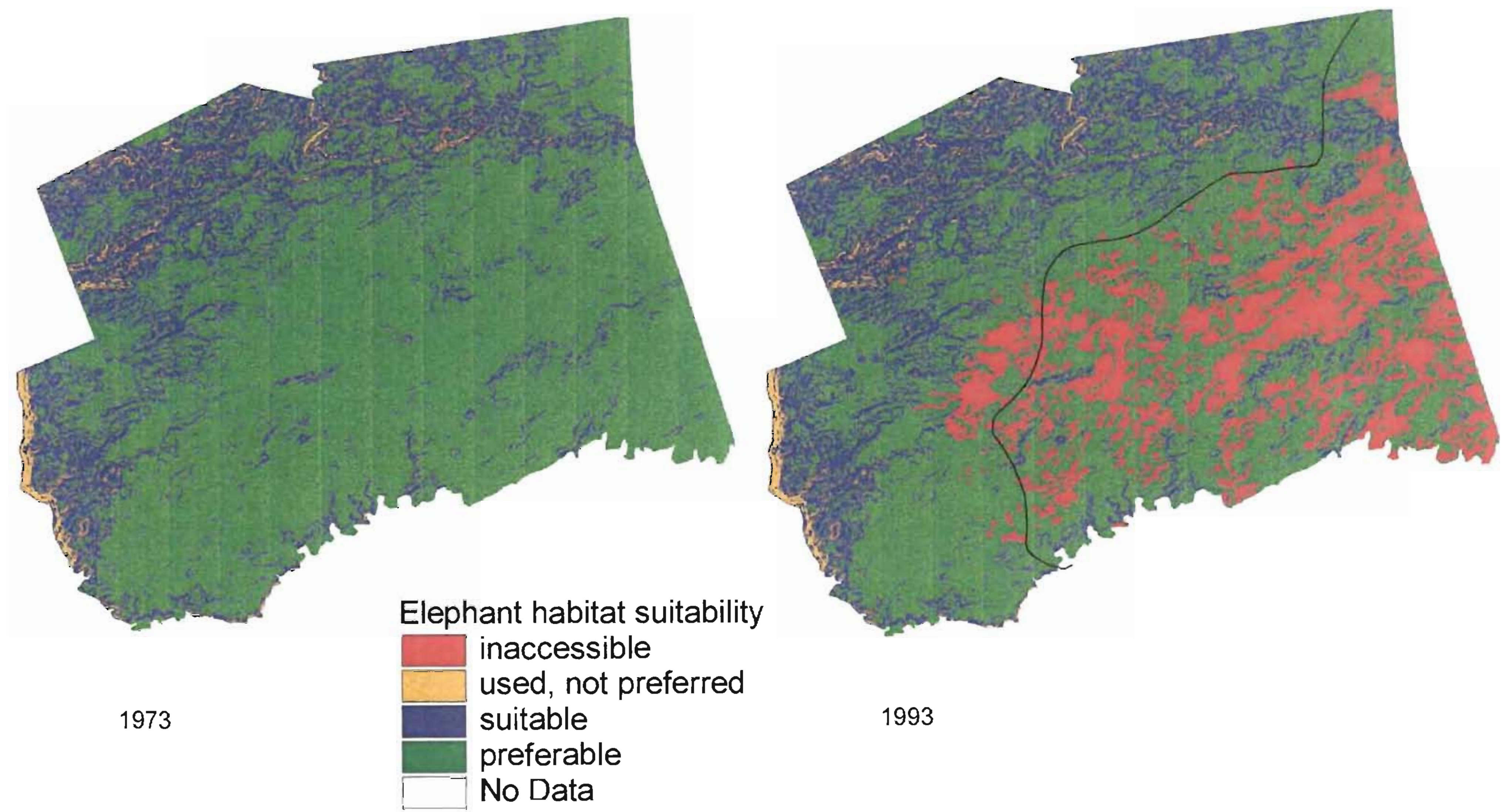

Fig. 30 Habitat suitability maps for elephant in 1973 and 1993 in Kanyati

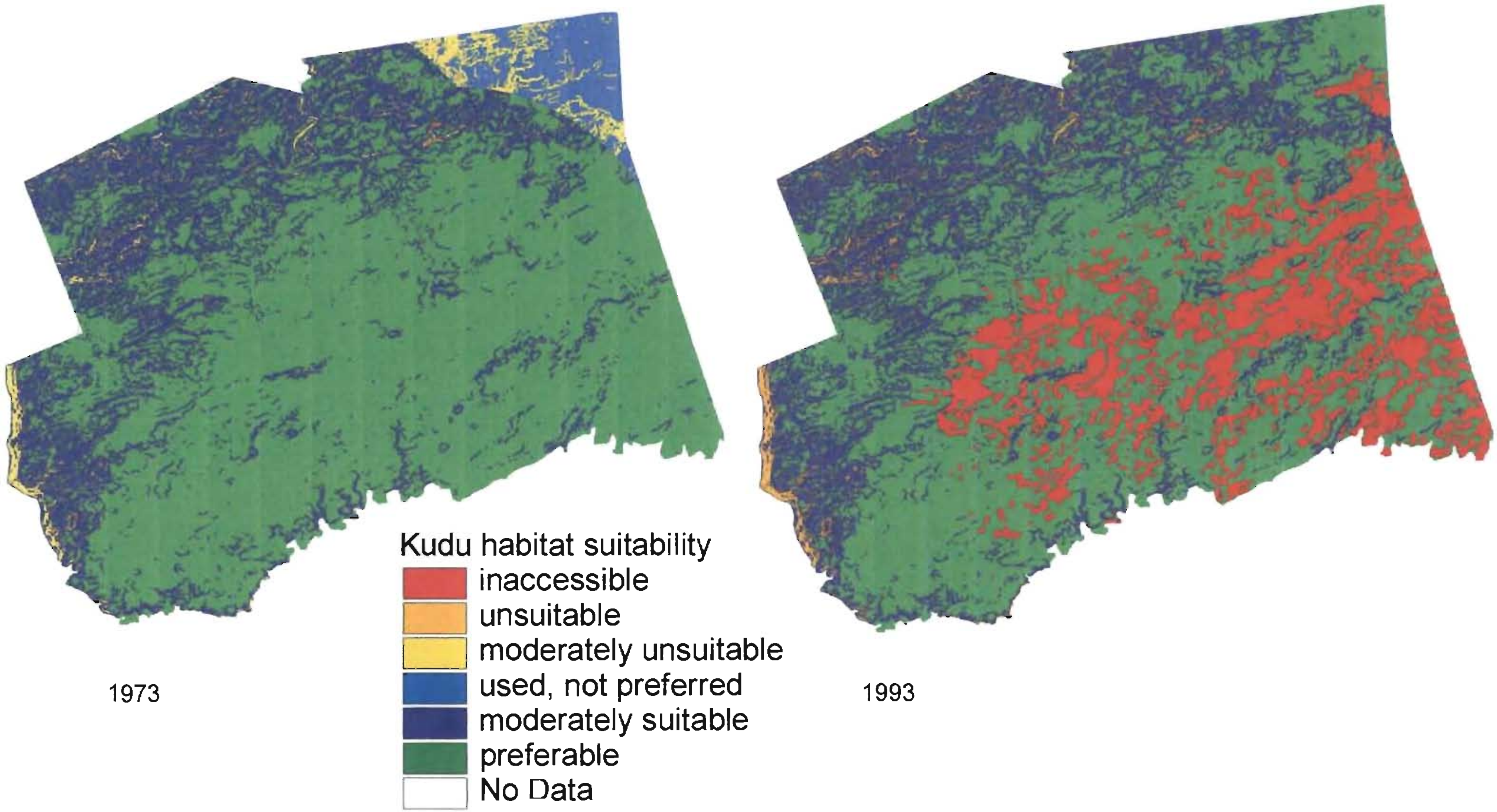

Fig. 31 Habitat suitability maps for kudu in 1973 and 1993 in Kanyati

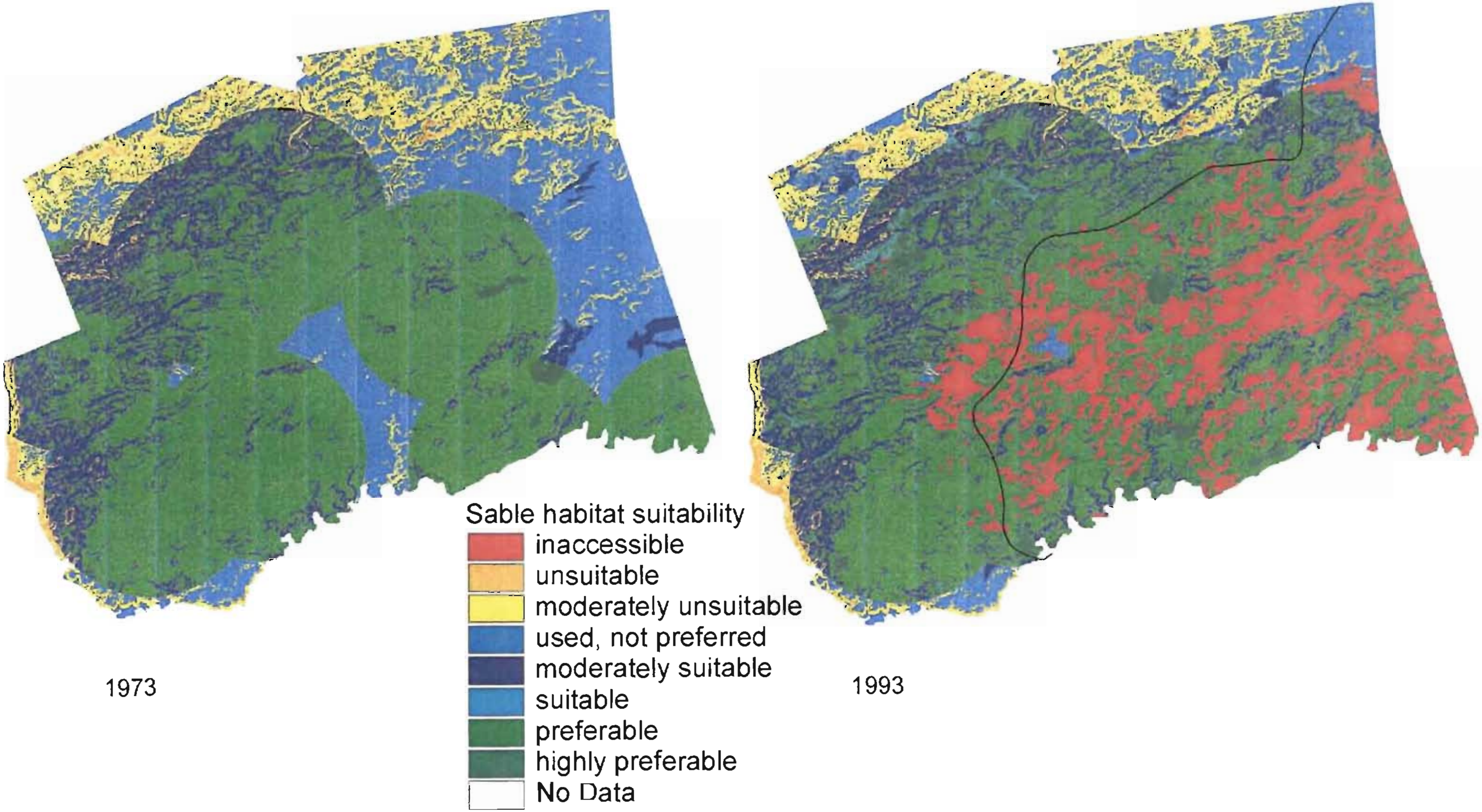

Fig. 32 Habitat suitability maps for sable in 1973 and 1993 in Kanyati

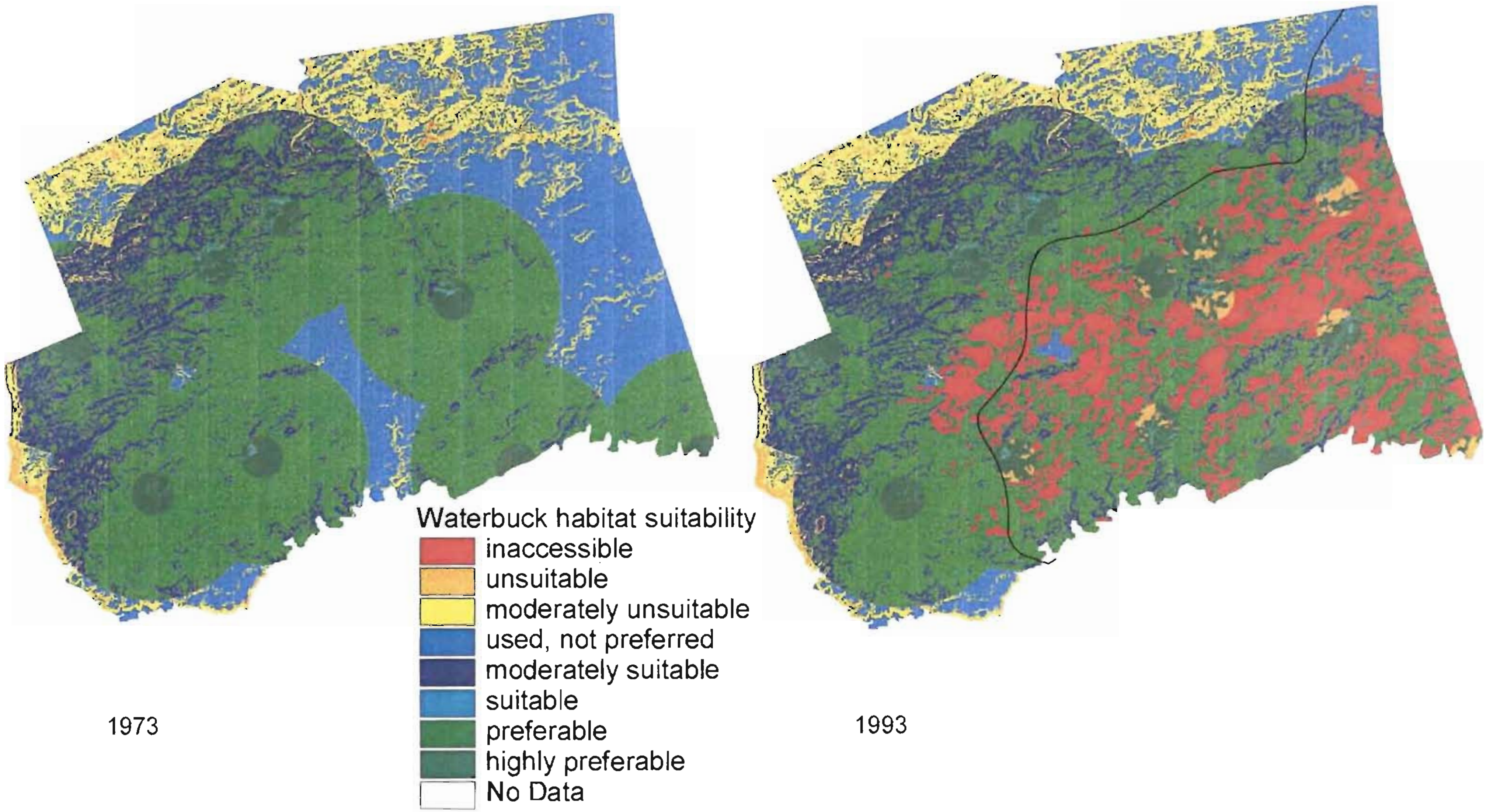

Fig. 33 Habitat suitability maps for waterbuck in 1973 and 1993 in Kanyati

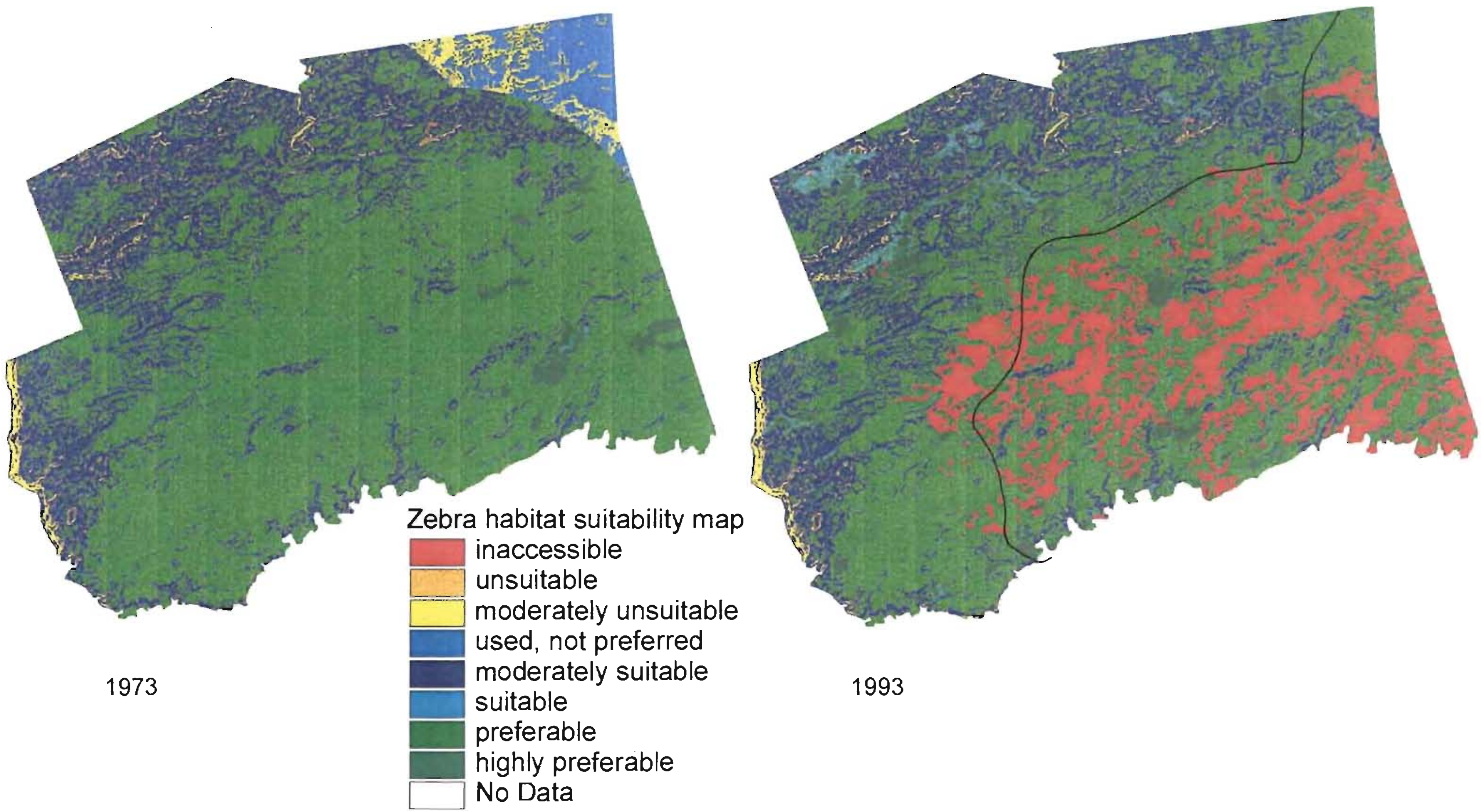

Fig. 34 Habitat suitability maps for zebra in 1973 and 1993 in Kanyati

The habitat suitability map for buffalo is shown in Fig. 28 and the areas in each class of habitat shown in Fig. 35. The total amount of suitable land was reduced by approximately 72 km^2 by 1993 (Table 10). The number of areas larger than 5 km^2 of suitable buffalo habitat in 1973 was 5 with a total area of 463.8 km^2 compared with a total area of 333.1 km^2 in 1993. This gives some indication of fragmentation of habitat. Only 2 of the areas in 1993 which were suitable habitat and larger than 5 km^2 were found in the settled area (both within 0.5 km^2 from the game fence). There was a large area of 254 km^2 in 1993, which was fairly perforated and fragmented, with the largest contiguous section situated in the southern wildlife area. Buffalo have large home ranges and congregate in herds, so it is unlikely that they would venture into suitable habitat areas in the settled area, but would use the suitable habitat in the wildlife area.

The majority of the study site was found to have low values of suitability for bushbuck for both years, with a very slight increase of more suitable habitat in 1993 probably due to increased number of waterpoints in the settled area (Table 10, Fig.36). The most preferred habitat for bushbuck is in the thick, riverine vegetation fringing watercourses especially when this coincides with proximity to the waterpoints in the dry season. (A distance of 50 metres from main rivers was considered sufficient to represent this riverine vegetation, due to the steep terrain bordering rivers). This preferred habitat in the settled area in 1993 has been encroached by unsuitable habitat (cultivated and grazed/cleared land) as is shown in Fig. 29. Note the areas within 1 km of waterpoints in the dry season in the settled area, shown in a bright green colour. There are some corridors of suitable habitat (riverine vegetation) linking some of the areas within 1 km of waterpoints in the settled area but as buckbuck are secretive animals they may not use these areas because of their proximity to settlement. The corridors are also fairly narrow and in some cases fragmented by cultivated and grazed/cleared land. Analysis of suitable habitat areas larger than or equal to 0.06 km^2 (home range of bushbuck) with distance from the game fence into the settled area, showed that 35% were found within 0.5 to 2 km from the fence. Bushbuck would be highly unlikely to traverse through settled and cultivated land to get to suitable habitat further than this, so the rest of these suitable habitats would be inaccessible.

Elephant have the most versatile habitat requirements as they are habitat generalists and are able to travel great distances without water, across steep terrain and through settled areas. They are probably the least affected by fragmentation for these reasons, as they are able to utilise habitats as these change, but also are able to traverse less suitable habitat. The habitat suitability maps are shown in Fig. 30. The total amount of suitable habitat was reduced by approximately 107 km^2. Areas of each class of habitat in 1973 and 1993 are shown in Fig. 37. This shows an increase in the least suitable habitat in 1993, and the decrease in the areas of the most suitable habitat class. The latter included the largest geographical feature in the area which was 411.6 km^2 in 1973 and 298.1 km^2 in 1993, when it was also within the most suitable habitat class. There were only two areas of suitable habitat which were more than 5 km^2 in 1993, in or intersecting the settled area. Smaller areas of suitable habitat in the settled area were mostly found between 5 and 10 km from the game fence, with lower frequencies distributed relatively evenly from 0.5 km to 5km.

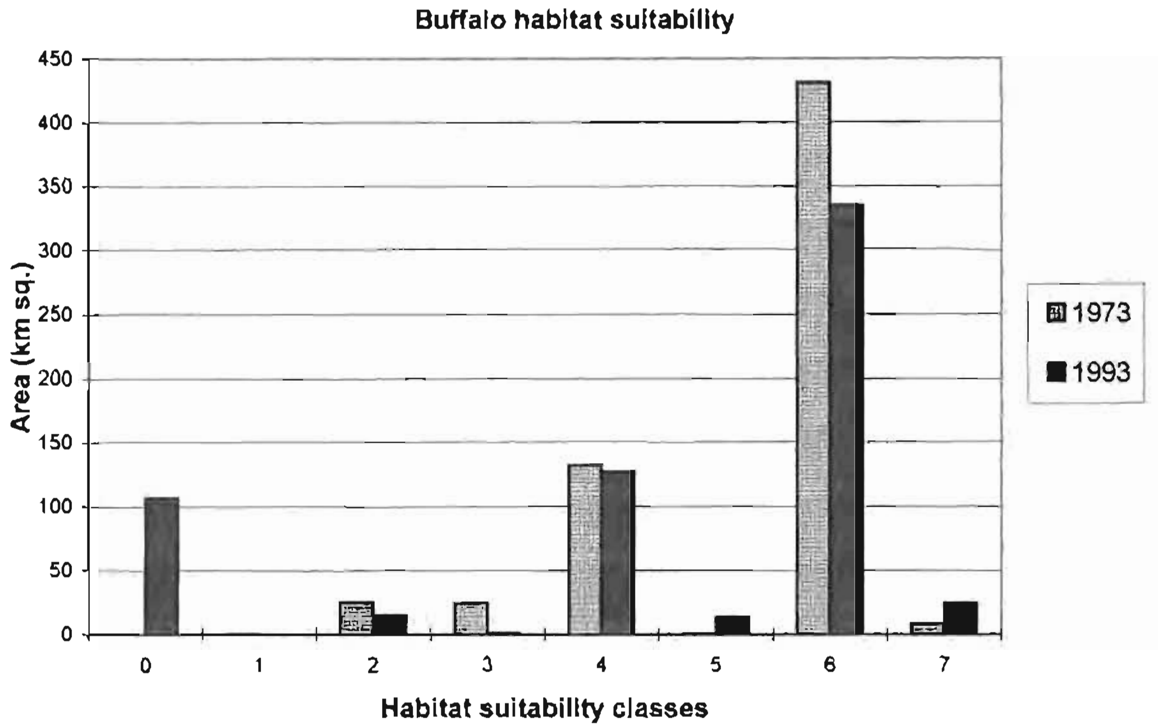

Fig. 35 Area (km2) of land for buffalo in each habitat suitability class for 1973 and 1993

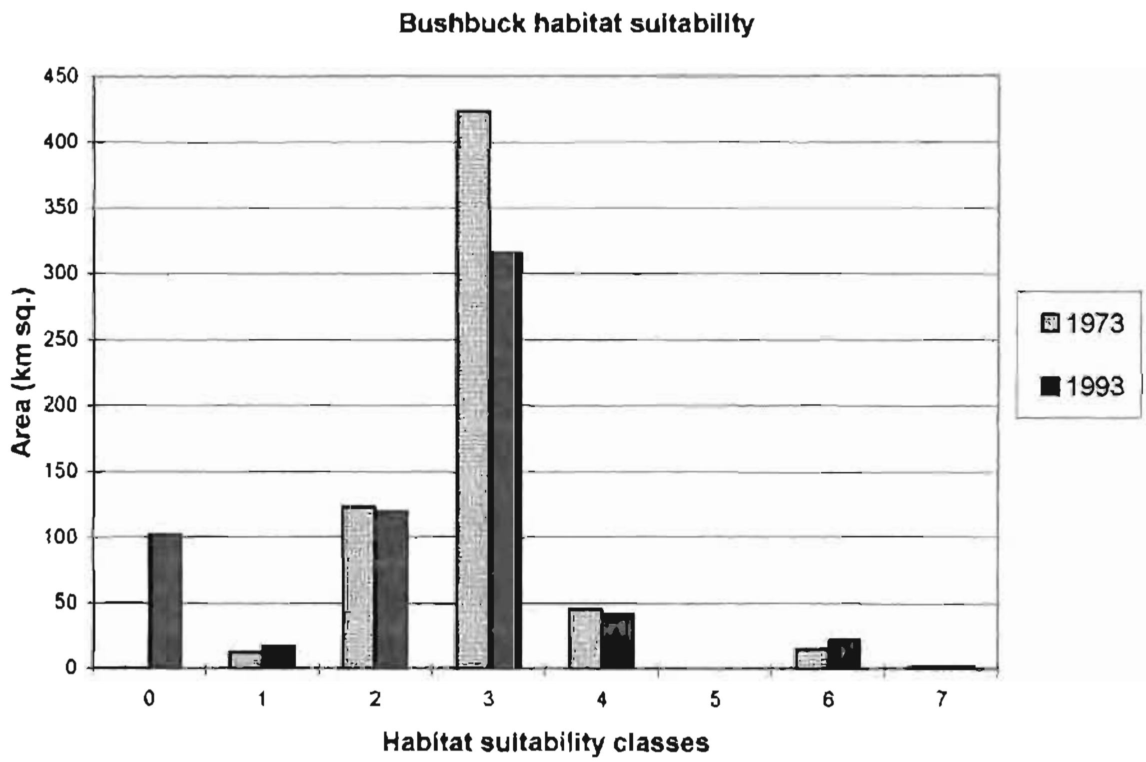

Fig. 36 Area (km2) of land for bushbuck in each habitat suitability class for 1973 and 1993

The habitat suitability maps (Fig. 31) and areas within each suitability class for kudu (Fig. 38) showed similar patterns to those of elephant. The total amount of suitable habitat was reduced by approximately 72 km^2 (the same amount as for buffalo, see Table 10). Kudu differ from elephant in that they prefer to be in closer proximity to water than elephant (approximately 10 km from water). Kudu have varying home ranges, from 1-10 km^2 for herds and females, and up to 32 km^2 for males. There were only 4 areas of suitable habitat in 1993 which were larger than 10 km^2, which were mostly in the wildlife area. One of the areas comprised 298 km^2 and stretched across the southern part of the wildlife area and into the settled area. It was more perforated and fragmented in the settled area by areas of less suitable habitat. This pattern of the largest area of habitat with the same location, becoming smaller and fragmented by 1993 was shared by all the species. There were only two suitable habitat areas larger than 10 km^2 in 1993 which intersected or were within the settled area and these were found within 0.5 km^2 from the game fence. These could conceivably be considered areas of prime habitat for kudu. Kudu do venture into settled areas at night to feed on crops.

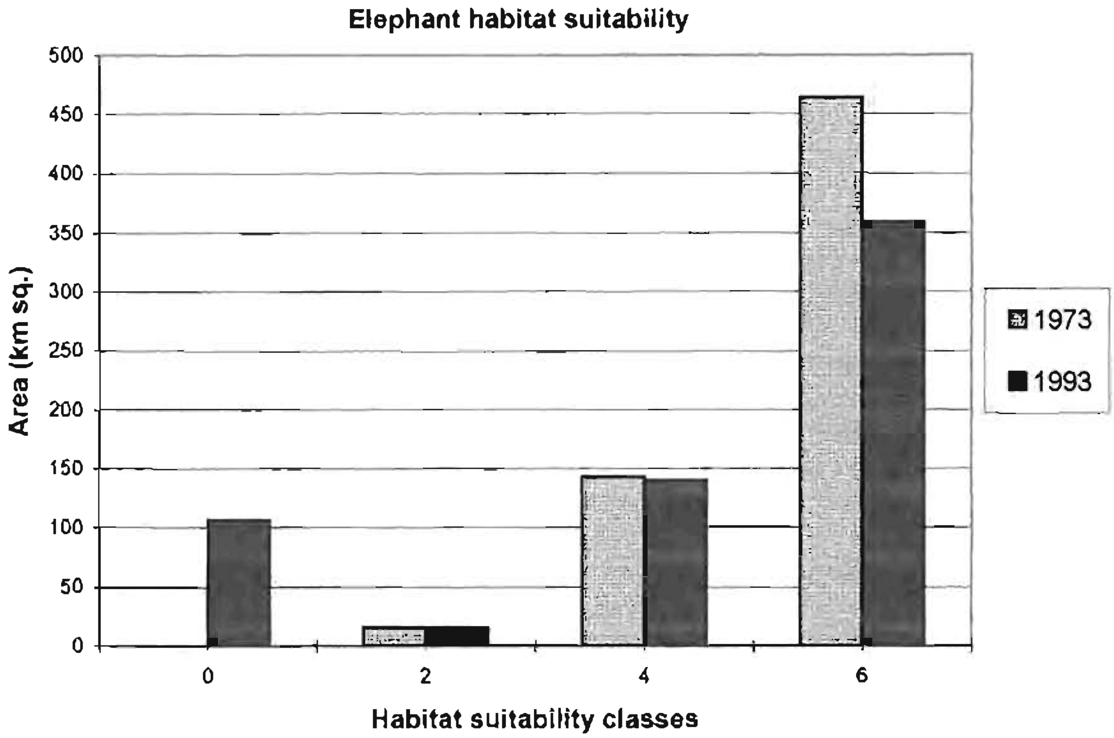

Fig. 37 Area (km2) of land for elephant in each habitat suitability class for 1973 and 1993

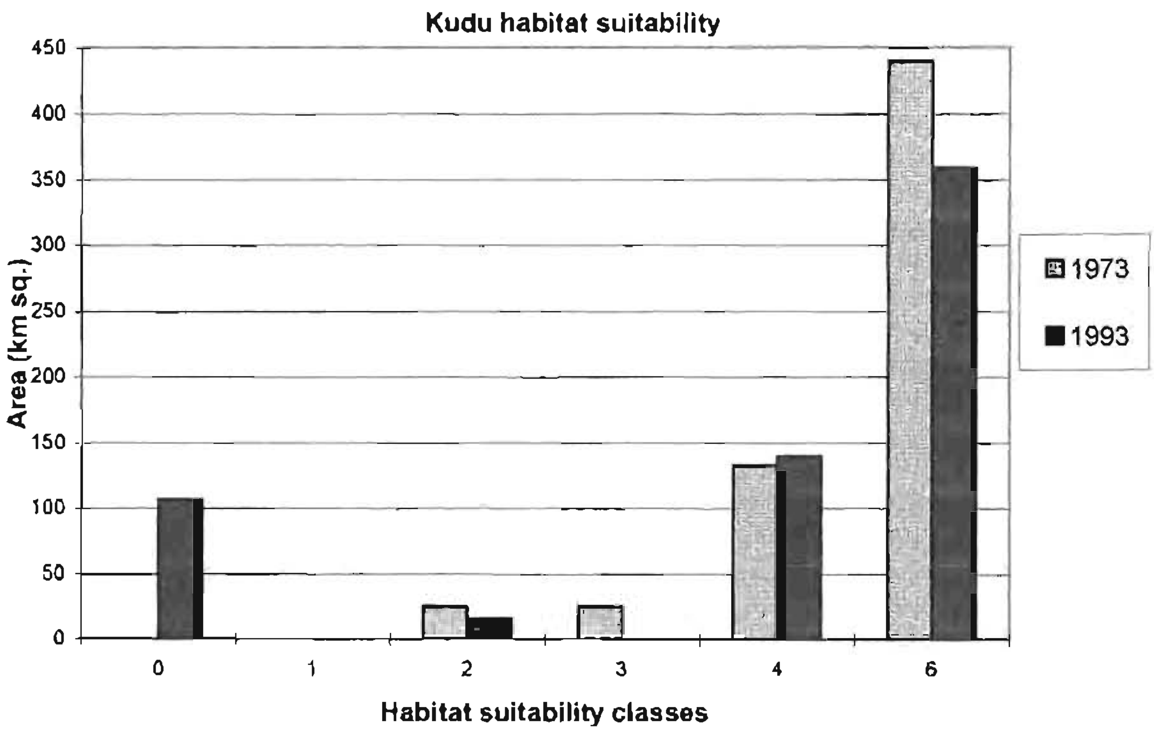

Fig. 38 Area (km2) of land for kudu in each habitat suitability class for 1973 and 1993

The habitat suitability maps of sable are shown in Fig. 32 and areas within each suitability class in Fig. 39. The total areas of suitable habitat, and unsuitable habitat remained approximately the same from 1973 to 1993 (see Table 10) with areas of suitable habitat comprising a higher proportion of the study site. The number of areas of suitable habitat for sable, equal to or larger than 0.4 km^2 (home range for sable in the dry season) was 124 in 1993. Only 25 of these were wholly or partially within the settled area, and surrounded and perforated by less suitable land. 36% of the suitable habitat in the settled area were found within 0.5 km and 2km from the game fence, with 28% within 0.5 km (which included the largest contiguous area of all suitable habitats). 24% were found between 3 and 4km and 32% were found between 5 and 10 km from the game fence. Sable would be unlikely to venture into the settled area to access these habitats further than a couple of kilometres, so primarily utilise suitable habitats in the wildlife area.

Waterbuck showed similar patterns as sable (see Fig. 33), with no change in amounts of suitable and unsuitable areas, with approximately the same amounts of suitable habitats (see Table 10) and distribution through the different classes (see Fig. 40). Only 24 features out of a total of 10 086 were suitable habitat greater than or equal to 1 km^2, which was taken as the average home range for waterbuck. Of these, only 12 were found partially or wholly within the settled area with the largest area found within 0.5 km^2 of the game fence. There was a decline in the number of suitable areas of 1 km^2 with distance from the game fence from 0.5 to 3km, and then an increase in numbers at 4km, which similarly dropped to 16-km away (maximum distance from game fence). It is unlikely that waterbuck will venture more than a few kilometres into the settled area and will probably be within the largest contiguous area, which falls within the settled, and the wildlife areas.

Zebra habitat suitability maps are shown in Fig. 33 and the areas in each class are shown in Fig. 41. The total amount of suitable habitats was reduced by 73 km^2, mostly in the 'preferable' class of suitability, which included the largest area of suitable habitat. Zebra have large home ranges and travel in large herds, but are not territorial (so that home ranges of different herds overlap). There were only 5 suitable habitat areas equal than or larger than 5 km^2, and only 2 of these were found intersecting the settled area (within 0.5 km from the game fence). One of these was the largest contiguous area of 254 km^2, which would most likely be utilised by the zebra, to pass from the wildlife area at least into the edge of the settled area from the game fence.

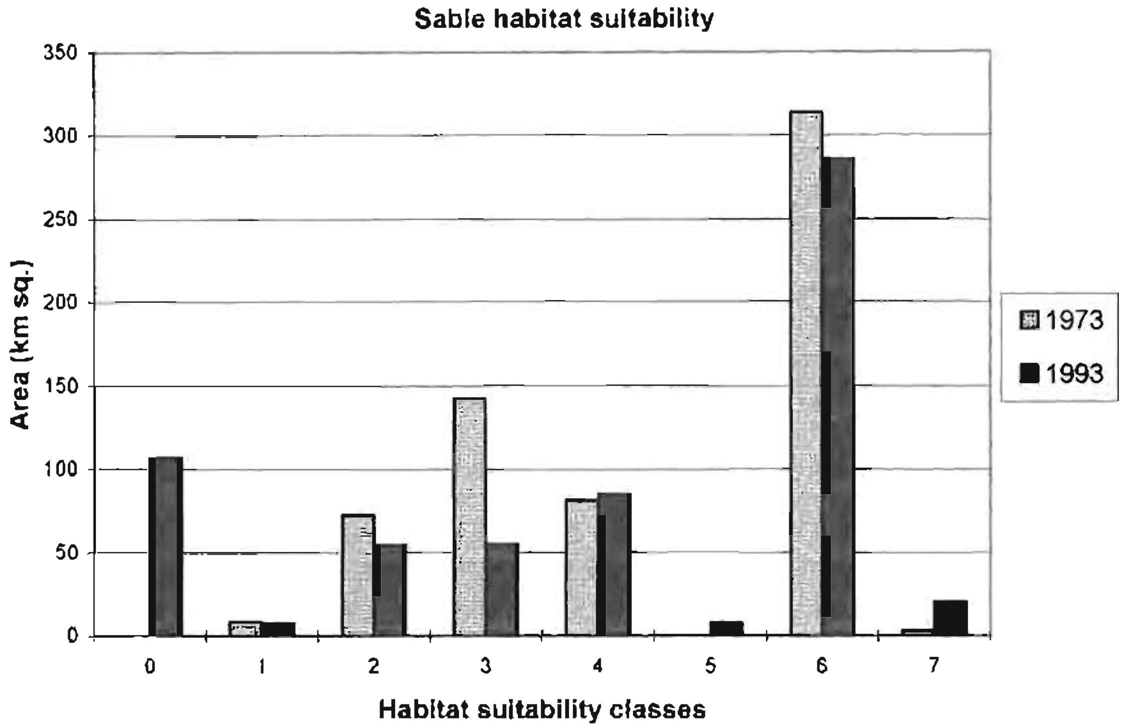

Fig. 39 Area (km2) of land for sable in each habitat suitability class for 1973 and 1993

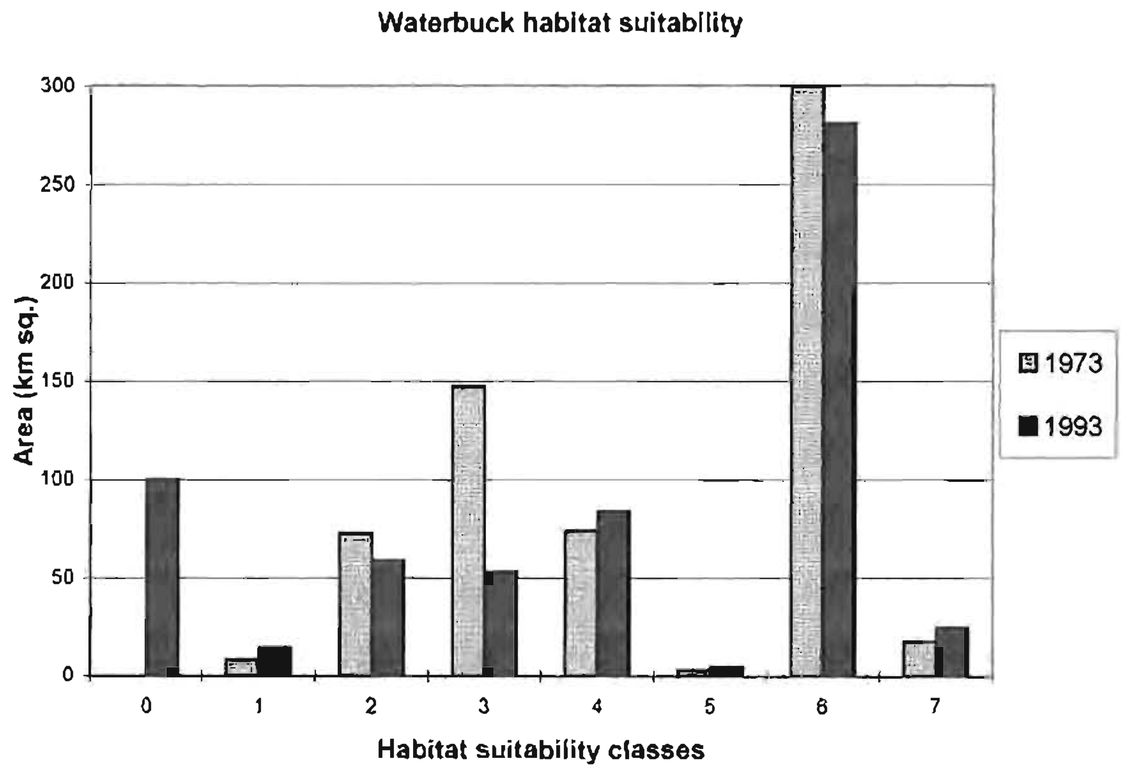

Fig. 40 Area (km2) of land for waterbuck in each habitat suitability class for 1973 and 1993

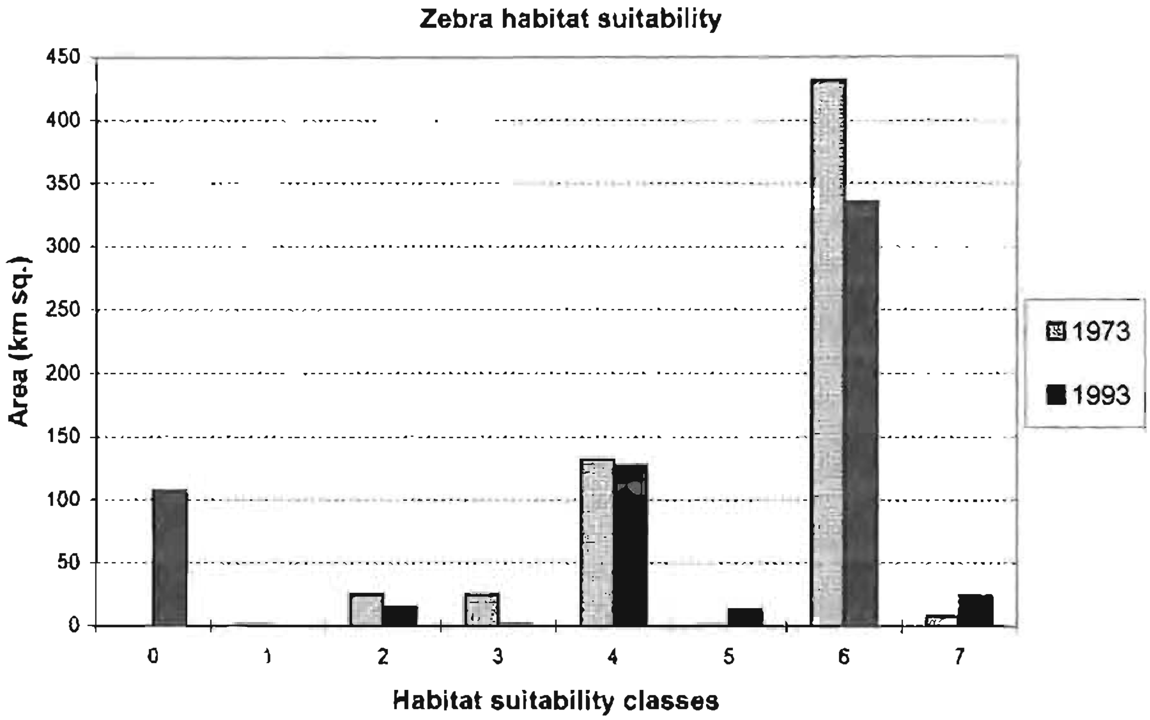

Fig. 41 Area (km2) of land for zebra in each habitat suitability class for 1973 & 1993

These results show that there would be an ecological effect of habitat fragmentation, especially in the substitution by less suitable habitats in the settled area. Availability of water offsets a possible reduction in habitat for sable and waterbuck, showing no change in the total amount of suitable habitat, but this does not reflect that large areas of suitable habitat that have been fragmented. Large contiguous areas of suitable habitat for all species which were found to be in the same location, were reduced in size and perforated and fragmented by less suitable areas. Bushbuck would be the most significantly affected by fragmentation of its habitat due to its small home range and tendency to avoid settled areas. This would make it less likely for them to traverse these areas in order to utilise habitat patches within the settled area, effectively excluding most of that area whether suitable or not. Elephant would be the least affected by habitat fragmentation in spite of their large body size and food requirements, due to their ability to utilise various habitats even if they are within settled areas. Most of the species would probably remain within the wildlife area with some moving into the settled area occasionally for food or water.

Preliminary results from an unpublished field study in Kanyati by Gardiner (A. Gardiner, 1999, personal communication) show that bird species abundance varied between the two seasons according to seasons. In the dry season (sampling in November) the birds seem to be more abundant in the wildlife area. In the wet season (sampling in March) the abundance of birds increased, possibly linked with harvesting so that there would be more seeds, crops and insects (ie. increased diversity of habitats). One particular transect had some of the highest abundance of birds, but included land used for grazing as opposed to a cultivated field, so constituted tree cover but little grass cover.

This may be attributable to greater habitat diversity with more insects and seeds available. Bird species are more able to cross less suitable land to get to suitable patches than many large mammals and would have finer-grained patterns of habitat use. The patterns of their habitat use and distributions at fine scales are difficult to ascertain in miombo because of the clumped distribution due to formations of bird parties (P.Frost, personal communication[13]).

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6. DISCUSSION & CONCLUSIONS

During 1973 to 1993 in Kanyati Communal Land, miombo woodland and termitaria woodland were fragmented by cultivation, grazed/cleared and settled land and to a lesser extent open miombo woodland, in Kanyati Communal Land. The increase in the number of spatial entities and decrease in areal extent of miombo and termitaria woodland showed this. Shrinkage and attrition accompanied the fragmentation in that there was a decrease in the spatial element sizes, and loss of these land cover types in some areas. These patterns are significant as miombo and termitaria woodland comprise the majority of the miombo woodland and provide habitat for wildlife species in the area. The influx of people who settled in the area from the mid-1980's onwards, was accompanied by a conversion of woodland to cultivated, grazed/cleared and settled land, and increase in the amount of tracks in the area by 1993. The tracks facilitate access and further expansion into areas. Conversion of miombo woodland and termitaria woodland to open woodland indicated that the tree cover and termitaria respectively, were reduced. Termitaria are utilised by a range of species for food and shelter, but also by farmers for cultivation because of their nutrient-rich soils, so that the characteristic dense vegetation is removed by intense use. The number of patches and total area of open woodland and cleared termitaria increased, and their average patch sizes decreased slightly. This may have been due to one or a combination of fire and animal activity (especially elephant) rather than human activity (such as firewood collection), as increases in open woodland in 1993 were in the wildlife area, quite far from the settled area. The areal extent of the open woodland remained the same in the settled area.

Measurement of the shape of patches/spatial entities was insightful when analysed in conjunction with other patch measures. The fractal dimensions increased significantly from 1973 to 1993 for all land cover types, especially for miombo and termitaria woodland. This showed that their patches/spatial elements had greater complexity of shape, more perimeter per area of spatial elements and possible decrease in patch interior which indicated fragmentation. The fractal dimensions of human influenced land covers such as cultivation and grazed/cleared land were not significantly lower than those of other land cover types as suggested in some of the literature. The latter studies investigated large tracts of commercial farmlands which tended to have simple geometric shapes with low perimeter to area ratios, compared with the smaller extents and more complex shapes of subsistence agriculture found in the communal lands in Zimbabwe. Hulshoff's shape indices complemented the fractal dimension measures by further describing the nature of the shapes. The miombo woodland and termitaria woodland in 1973 had many spatial elements or patches with relatively large interiors in relation to perimeters, and 1993 miombo woodland and settled areas had many patches with relatively small interiors. Every land cover type during the twenty-year period had increasing amounts of patches/spatial elements with relatively small interiors. Settled, cultivated, grazed/cleared land and cleared termitaria land displayed simpler shapes compared with other land cover types. The human influenced land cover types therefore did appear to have simpler shapes than miombo and termitaria woodland. The latter two land cover types had the highest values of shape complexity in 1993, although all land cover types showed a nominal increase in complexity in 1993 with the exception of miombo woodland - the dominant land cover type. The S2 value decrease in 1993 for miombo woodland matrix was not expected as it indicates that there was an overall decrease in the complexity of perimeter with decreased area. This may be expected in cases where the dominant land cover type such as agricultural land subsumes natural woodland (as in many northern hemisphere studies). Complexity was expected to increase in the case of Kanyati as the miombo woodland was the dominant land cover type fragmented by many patches of settled and cultivated land, hence overall perimeters increased. The fractal dimension figures reflect this suggesting that the S2 index may have been signicantly affected by many tiny fragments of miombo woodland in between cultivated and settled areas, which had simple shapes.

Kanyati Communal Land provides an opportunity to investigate patterns of land cover change with different land uses, as it is divided into wildlife and settled areas. It also allowed for comparison of the nature and extent of land transformation, in particular habitat fragmentation and loss, in Kanyati as a whole, with the wildlife and the settled area. The boundaries of the study site were administrative although the southern and part of the western boundaries are natural features (Kanyati river and Sanyati Gorge) although it is recognised that these are not necessarily ecological boundaries. The game fence was constructed for disease control, primarily to separate buffalo from cattle, but it has not been entirely effective in this regard as people and wildlife still move across it.

A change in extent, with analysis of the wildlife and settled areas separately, showed significant differences compared with analysis of the whole area. The rate of fragmentation and substition of miombo and termitaria woodland by other land cover types was higher in the settled area, although just over half of this land was still miombo woodland. The wildlife area had a higher proportion of miombo woodland which decreased slightly by 1993 compared with settled area. The quality of the miombo woodland as habitat in the settled area may be affected by the adjacency of suitable habitat patches to unsuitable areas of settlement and cultivation.

The largest proportion of each of the land cover types were found on slopes of 0 to 8 degrees, with miombo woodland, termitaria woodland and cleared termitaria woodland found on higher slopes compared with other land cover types. Open woodland was found on higher slopes in 1993 compared with 1973, with a much lower proportion of land found in the smallest slope class (0 to 4 degrees) in 1993. Cultivated, grazed/cleared and settled land were mostly found on relatively flat land, of 0 to 4 degrees slope, with grazed/cleared land having larger proportions than cultivated and settled land on slightly higher slopes. Grazing herds would be able to forage on steeper slopes whereas it is preferable for cultivated land to be in flat areas. The wildlife area showed much higher proportions of land with steeper slopes than the settled area (more than double the area), as it includes the escarpment area and broken terrain. This is part of the reason why this area was designated a wildlife area, as it is unsuitable for cultivation in addition to having shallow, low nutrient soils. Cultivated (probably fallow land) and grazed/cleared land still occurred in the wildlife area in 1993 although not permitted beyond the game fence.

Cultivated, grazed/cleared and settled land were primarily found in the settled area within 1 km of rivers. It is recognised that proximity to main rivers derived from topographic maps, may not always reflect availability of water as this depends on the season. A larger proportion of grazed/cleared land was found further away from rivers compared with cultivation and settlement. This was probably due to grazing herds being able to move further from water as opposed to the location of cultivated land which would need to be closer to water supplies.

The mapping and analysis of habitat suitability in 1973 and 1993 for seven large herbivores gave some indication of the ecological effects of habitat fragmentation in Kanyati. Miombo woodland has low nutrient status so that low biomass tolerant herbivores such as elephant, buffalo and zebra, are ideally suited to this area. It is recognised that even if areas are identified as suitable, using simple habitat requirements for these species, this does not mean that these species will definitely occupy these areas. The habitat requirements of each species were sometimes difficult to determine and apply to Kanyati land cover because of different levels of habitat classification in the literature. Simple habitat suitability models using GIS are nonetheless important as they can provide a first estimation of habitat availability/non-availability. More detailed mapping would require expensive, long range field studies of feeding and home range behaviour of the species concerned. Buffalo, elephant, kudu and zebra showed a decrease in the amount of suitable habitat areas from 1973 to 1993. Bushbuck, sable and waterbuck did not show changes in 1993 as the amount of suitable and unsuitable habitat remained approximately the same. Any increases in unsuitable land, especially in the settled area such as cultivated, grazed/cleared and settled land were offset by an increase in suitable habitat caused by more waterpoints, such as dams in the settled areas. The use of waterpoints in the settled area by species would depend on how sensitive they are to the presence of people nearby. The areas classified as suitable to highly preferable, which are situated in the settled area may not necessarily be accessed by species depending on whether they will traverse unsuitable habitat to reach the habitat patches. Further analyses could include buffers around unsuitable habitat accounting for a particular species' response to proximity to settled areas if known. Bird species in Kanyati may not be as affected by suitable habitat adjacent to unsuitable habitat as they are more mobile than many other species. The impact of tracks on wildlife in the settled area and in particular their impingement on habitat may not be significant, as the majority of tracks and roads are not tarred and have relatively light traffic. The impact would also depend on the 'people tolerance' particular to each wildlife species.

Areas of habitat suitability were generally reduced in size and increased in number by 1993 showing habitat fragmentation and loss in some areas. All the habitat suitability maps showed a large, contiguous section of suitable habitat in 1973, which stretched from the southern part of the wildlife area, across the setteld area. These areas were perforated and fragmented by 1993 by unsuitable habitat areas, but nonetheless comprised the most likely part of Kanyati to be utilised by large mammalian herbivores. These would probably support resident wildlife populations especially those with large home ranges, some of which may venture across the game fence into the settled area for food and water. The distance travelled into the settled area would depend on the species. Elephant would be the least affected by habitat fragmentation as they are habitat generalists, travel long distances without water and are less disturbed by the presence of people than other species. The most affected species of the seven studied, would be bushbuck because of their small home ranges, requirements of being close to water and thickets and their aversion to settled areas.

The status of the current wildlife populations has been affected by the tsetse fly control hunting operations from the 1950's to 1970's which diminished the wildlife populations in the area. Poaching in the wildlife area has probably contributed to maintaining low densities of large herbivores in the area. Some reports state that poaching is carried out by people from other areas rather than the residents who favour wildlife. When wildlife is seen as a valuable asset for trophy hunting or ecotourism ventures through CAMPFIRE, the poaching may stop, especially if it is policed by the local communities. The wildlife area has the potential to be a corridor for wildlife joining Matusadona National Park and Omay Communal Lands to the west, to Charara Safari Area in the north west. This would facilitate gene flow between these areas and help conserve this relatively pristine miombo woodland area. Continued expansion of cultivated and settled land will further decrease the amount of miombo woodland in Kanyati. If this continues beyond the game fence into the wildlife area, suitable habitat for wildlife populations will be further reduced.

This method of analysing the spatial pattern using spatial distributions, patch size and shape is effective in describing land cover change over time. A simple assessment of total area of each land cover type would describe habitat loss but would fail to identify more subtle processes of land transformation such as habitat fragmentation. This was shown clearly with the habitat suitability mapping where estimates of total suitable land for species did not reflect that the size of the majority of these areas was too small for resident populations of large mammals. The distribution of suitable patches in the landscape is important, especially in the settled area where they were surrounded by less suitable habitat which may deter the movement of some species into these areas.

The use of high resolution, multi-spectral satellite imagery would be preferable for large extents as it would allow automated classification, but this is limited by high costs and to time periods of 1980 onwards. This would enable automated classification of data which is preferable to manual interpretation of remote-sensed data as this is prone to user bias and is harder to replicate. Aerial photography is more suitable to studies of land cover change over time in Zimbabwe. Land cover types derived from remotely sensed data and mapping thereof involves a certain amount of abstraction and data reduction. A simplification of reality is needed to make the information more accessible and manageable, which serves a particular purpose which in this case was to provide a means of describing spatial patterns of land cover change. Caution must be taken in using information collected at one scale, to infer generalisations at different scales.

Finally, further research questions arise from this study, such as how do these land cover change patterns compare with those of an area of high elephant densities, such as Matusadona National Park; and with a densely populated communal land?

To what extent are patches of woodland in the settled areas being used by wildlife species in Kanyati which is not as densely populated as other communal lands in Zimbabwe? How do termitaria contribute to species diversity in an area, as hotspots of activity for birds, mammals and other species? Research into these questions would continue this initial study of the spatial patterns of land cover change at this scale, and their effects on biodiversity in an area.

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