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A multi-method analysis of forest fragmentation and loss: The case of ward 11, Chiredzi District of Zimbabwe

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Forest fragmentation and loss seriously affect biodiversity. There is need to monitor and assess forest fragmentation and loss in communal areas for effective biodiversity management. In this study, we analysed the extent of forest fragmentation and loss in ward 11, Chiredzi district of Zimbabwe over a 14 year period (1989 to 2003). A multi-method design was adopted for triangulation and verification purposes. This involved the use of GIS and remote sensing techniques for analysis of satellite images of 1989 and 2003. Fragstats was used to compute the density, size and variation of patches between the two years. A patch area method for determining optimum quadrat size was proposed from for observations and measurements were done. Questionnaire surveys were used to complement data produced through GIS analysis. The non aligned block sampling design in which sample locations were randomly nested was used. Questionnaire surveys were used to collect qualitative data. Results show that there is ecologically significant fragmentation and loss of forest. Forest patches increased by 58.04% between 1989 and 2003. A loss of 32.47% of forest area was estimated. People's perceptions confirm the conclusion that the forest has been significantly fragmented and lost due to collaborative effects of climatic changes and human activities.

Key words: Forest fragmentation and loss, multi-method design, remote sensing, geographic information system, Fragstats, patch area method.

INTRODUCTION

Forest fragmentation is a process during which a large expanse of forest habitat is transformed into a number of smaller patches of smaller total area, isolated from each other by a matrix of habitats unlike the original (Haila, 1999; Fahrig, 2003). By this definition, a landscape can be qualitatively categorized as either continuous or fragmented, where the fragmented landscape represents the endpoint of the process of fragmentation. Fragmentation and loss are recognized as major threats for the conservation of biodiversity and ecological functions of forests (Harris, 1984; Forman, 1995; Rochelle et al., 1999; Loyn and McAlpine, 2001).

The harmful consequences of forest fragmentation for certain species is derived from three main causes: reduction of the size (area) of the remaining forest patches, increased isolation of the fragments and loss of overall connectivity, and increased edge effect and disturbances from the surroundings (Saunders et al., 1991; Forman, 1995; Haila, 1999; Santos and Tellerı´a, 1999). It affects the abundance, richness and dispersal ability of forest-dwelling species (Lida and Nakashizuka, 1995, Gill and Williams, 1996, Gibson et al., 1988; Merriam, 1998; Haila, 1999; Rochelle et al., 1999; Santos and Tellerı´a, 1999; Soledad Garcı´a-Gigorro and

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Santiago Saura, 2004).

The most obvious effect of the process of fragmentation is the removal of forest habitat. This has led many researchers to measure the degree of habitat fragmentation as simply the amount of habitat remaining on the landscape (Carlson and Hartman, 2001; Fuller, 2001; Golden and Crist, 2000; Hargis et al., 1999; Robinson et al., 1999; Summerville and Crist, 2001; Virgos, 2001; Robinson et al., 1995). When ecologists think of fragmentation, the word invokes more than habitat removal: it does not cause only loss of the amount of habitat, but by creating small, isolated patches it also changes the properties of the remaining habitat" (van den Berg et al., 2001).

Over time, many species of plants and animals have evolved to depend on one another. For example, some plants can only be pollinated by a certain kind of bird or insect, (Soper, 2000). The complex relationships between species are often disrupted when organisms are transported to new places or a new element is introduced, (Soper, 2000; Wo Okot-Uma, 2000). This supports Jacobs (1979)'s view that habitat fragmentation results in the split of a species group into smaller groups which are more vulnerable to environmental changes.

Existing forests serve a multitude of functions vital for mankind in addition to providing wood as a renewable resource. Thus, there is a paramount need to conserve forest resources and to implement measures to increase forest biomass at the same time. The global total area of forests (excluding other wooded lands) at present amounts to about 4 billion ha, roughly half of which is tropical forests, and of the remainder, temperate and boreal forests account for one third and two thirds, respectively. During the course of human history, roughly 2 billion ha have been lost due to various human activities, mostly in the temperate zones.

Clearing natural habitats for agriculture, forestry, urban development and water projects reduce their effectiveness in providing shelter for species which live there (Forman, 1997; Jackson and Jackson, 1998; Green et al., 2000). For a particular species, certain conditions of external parameters, for example temperature, humidity and resources like food and space must exist for the species to survive, grow, reproduce and maintain a viable population (Jackson and Jackson, 1998).

There is prevalence of the slash and burn type of agriculture which, in the 1980s, cost the world 100 000 km^2 per year of tropical rainforest, (Munowenyu, 1996). In some areas especially in Africa, large sections of tropical rainforests are cleared for raising cash crops like sugarcane, banana, pineapple, soya bean and palm oil for export (Miller and Spoolman, 2009). This has significantly contributed to the fragmentation and loss of forest habitat posing a deluge of impacts on vegetative and animal species diversity.

Specifically, in Zimbabwe it is estimated that 70 000 hectares of woodland are cleared annually for agricultural activities (Chenje et al., 1998). The profitability of wood as a burning fuel, and as a useful industrial raw material has overridden environmental reason, threatening ecological systems, pollution, and destroying forest health and biodiversity (Gogo, 2012).

Over 46 015 hectares of forests have been destroyed and 1,38 million cubic metres of firewood burnt to cure part of the 127 million kilogrammes of tobacco delivered to the auction floors (Manica Post, 2011). Farmers often remove trees from grazing lands as well as arable lands. Woodland areas are converted to agriculture either as informal annexation of woodlands by individual farmers or through government resettlement schemes (Chenje et al., 1998).

Wild animals are reported to have migrated due to these environmental changes. While habitat fragmentation and loss are clearly visible in this area, no study has been carried out to measure their extent and related impacts on flora and fauna species diversity. This study seeks to assess the extent of habitat fragmentation and loss and their impacts on flora and fauna species, diversity.

Given the impending repercussions of natural phenolmena and human activities that are the driving forces behind habitat fragmentation and loss, there is need to come up with strategies and habitat management policies that minimise their impacts. The starting point is research related to forest fragmentation and loss and their impact on various ecosystem functions. Currently, there is paucity of quantitative and qualitative data to demonstrate the extent to which fragmentation and loss have affected vegetative and animal species diversity.

This study aimed to assess forest fragmentation and loss in Chikombedzi ward 11 providing quantitative and qualitative data to demonstrate the changes that have taken place over time.

MATERIALS AND METHODS

Study area

The study was carried out in Chikombedzi area ward 11 in Chiredzi district which is in the south eastern part of Zimbabwe (Figure 1).

The area is generally hot and dry. The total human population of the ward is approximately 15 000. The majority of the population is peasant farmers. Ward 11 is separated from ward 10 by a railway line to the north of the ward. To the south, the ward is separated from ward 13 by Mwenezi River. To the east, the ward shares the boundary with ward 12, which are small scale farms of the colonial African purchase area and to the west, it shares boundary with former large scale cattle ranches which are currently occupied under the Land Reform Program.

The study area falls in a region which might be affected in the near future by intensive human activities and this justifies the necessity of similar studies. The dominant type of vegetation is *spiciformis* and *Julbernardia globiflora*, Miombo woodland, (Campbell et al., 1988), make part of woody vegetation. *Parinari* tree bush Savannah with continuous or discontinuous grass cover pattern, topography, soil type and human disturbance. *Brachystegia* depending on the soil moisture regime (Zhou, 2004).

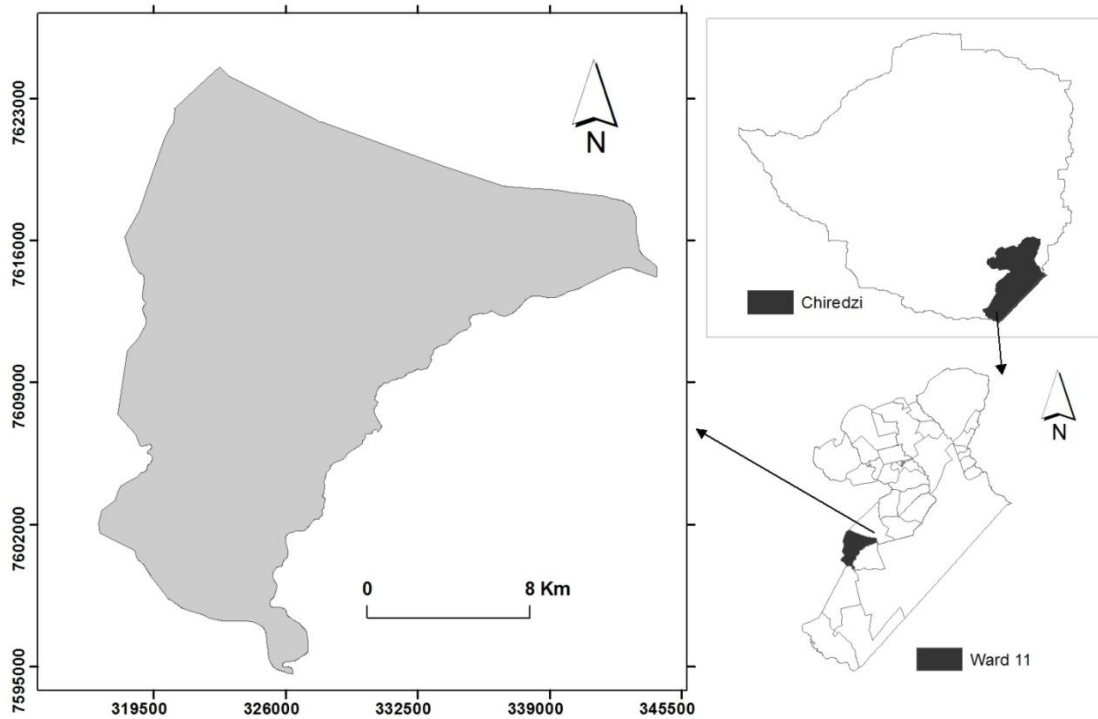

Figure 1. Map of the study area.

Vegetation species composition and variants is mostly determined by rainfall *curatellifolia* can also be found in pure stand or in combination with *Burkea African* and *Terminalia serice* and they are mainly found in well drained middle slopes and on upland soils. However, few vegetation of this type remains in its pristine state due to clearing of land for agriculture. Woody tree species are dominated by the drought tolerant Mopane (*Colophospermum mopane*), baobab (*Adansonia digitata*), *Commiphora* spp., *Kirkia/cuminate* and *Acacia* tree species (Zhou, 2004; Chenje et al., 1998).

In ward 11 of Chikombedzi, there has been significant logging of trees, proliferation of veld fires and other various human activities that have led to loss of natural vegetation exposing soil to erosion resulting in the siltation of water bodies. Infrastructural development such as roads, urban areas, schools and clinics as well as population growth have exacerbated habitat exploitation resulting in significantly visible fragmentation and loss. The dominance of farmers could only mean an increase in land clearance for crop production, which contributes to the problem of fragmentation and loss.

Ground sampling design

A nested non-aligned block sampling design, adopted by Chapungu and Yekeye (2013) in a study estimating species diversity in a communal landscape, was used in which sample locations were randomly nested as shown in Figure 2.

This design was used because it allows multi-scale assessment of variables in which small and large variations over large areas will be captured (Urban, 2002; Chapungu and Yekeye, 2013). A grid of 12500 x 12500 m was drawn within the ward boundaries on satellite images using the Integrated Land and Water Information System (ILWIS), Geographic Information System (ITC, 2005). The grid was further subdivided into 25 sub-cells (grids of 2500 x 2500 m) from which three of them were randomly selected. The three selected cells of 2500 m were further divided into 25 micro cells (grids of 500 x 500 m) where three locations were randomly selected. The centre of the three selected 500 x 500 m grids were used for quadrat identification using a hand held Global Positioning System (GPS) receiver at less than 0.5 m error from the identified points.

Determination of optimum quadrat size

The size of the quadrat was determined using the proposed patch area method (Figure 3). This method involves plotting the number of patches identified in quadrats of successively larger size, so that the area enclosed by each one includes the area enclosed by the smaller one. In this study, 100 x 100 m up to 800 x 800 m plots were developed within each sampling unit to determine the cumulative frequency of identified forest patches. The data for each quadrat was recorded. The mean cumulative frequency (patch number) was then plotted against each plot size shown in Figure 5.

The quadrat with the optimum number of patches was the 500 x 500 m quadrat. Thus, it was the one adopted for this research.

Image processing

Landsat satellite images for 1989 and 2003 were downloaded and used to calculate percentage for each land cover type within Chikombedzi area, ward 11. The images were processed with Arc View GIS software. Supervised classification system was done using the maximum likelihood classifier. The land cover classes identified were used to determine the extent of habitat fragmentation and loss within the ward. Fragstats was used to compute the number, size and density of patches from the satellite

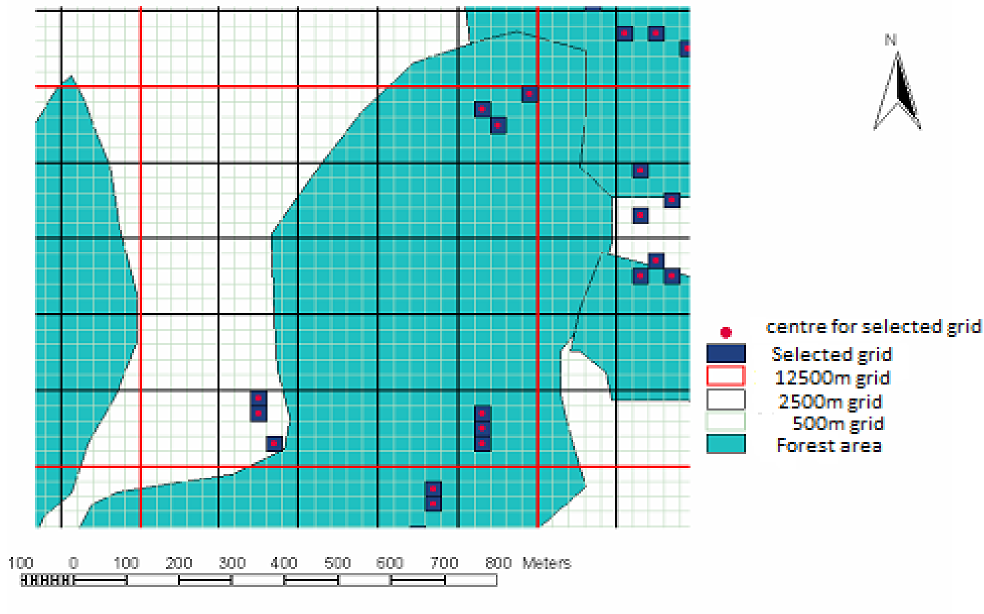

Figure 2. Non-aligned block sampling design using grids of 12500, 2500 and 500 m.

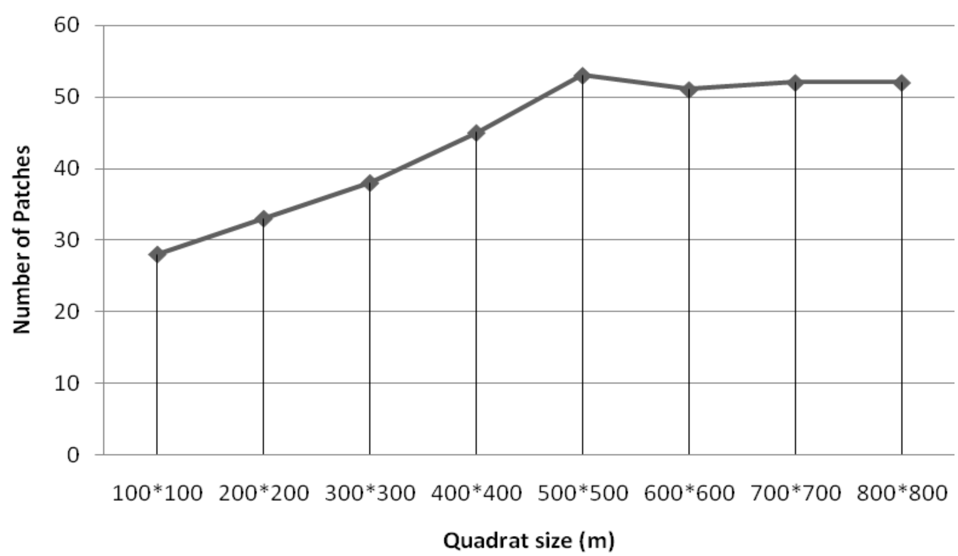

Figure 3. Determination of optimal quadrat size.

images. This facilitated comparison of patch size and number between the two years.

Observations and species physical counting

Direct observations were also used to collect data on the general state of the habitats, human interaction with ecosystem as well as the species available in the sampled areas. Species within the quadrats were also physically counted to establish species richness of the area.

Questionnaire survey

A total of 50 questionnaires were distributed to collect data on vegetative and animal species affected through habitat fragmentation and loss. Factors affecting habitat fragmentation and loss were also inferred through this method. Questionnaires were distributed in Chikombedzi, Pfumari, Chanienga, Chomupani, D16, D14, Mupakati, Gurungweni Chamagutise and Chagwaliva areas. People residing in the area for at least twenty years were targeted because they had stayed in the area long enough to notice the changes occurring in the area.

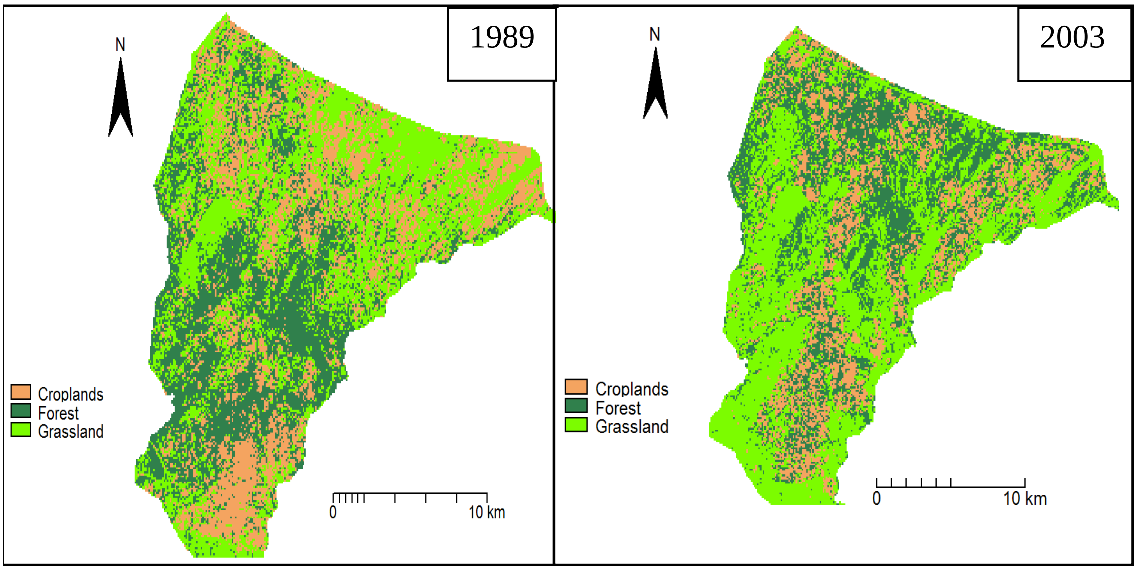

Figure 4. Habitat changes in Chikombedzi ward 11.

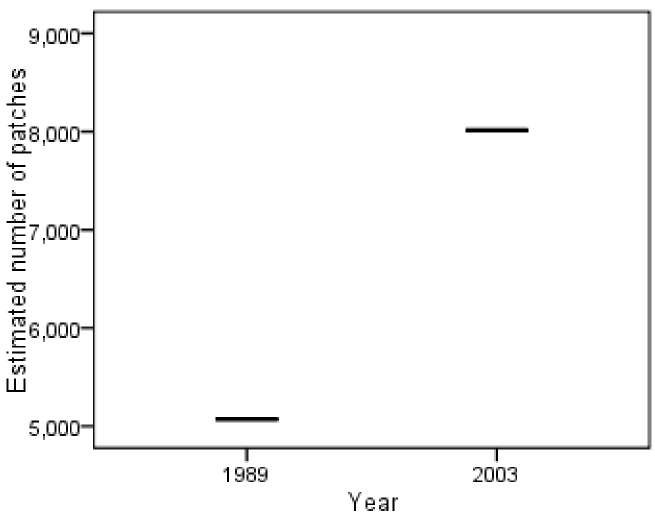

Figure 5. The number of forest patches in 1989 and 2003 (p>0.05).

Interviews

Interviews were also used to collect data from the individuals who could not participate in the questionnaire survey. Most of these individuals were elderly people who had a lot of information about the environmental changes occurring in the ward.

RESULTS AND DISCUSSIONS

Habitat fragmentation and loss

Land cover and land use maps for 1989 and 2003 were analysed and compared to assess the extent of habitat fragmentation. Satellite data from Landsat thematic maper imagery shows habitat changes between 1989 and 2003 (Figure 4).

Figure 4 shows differences in habitat coverage between the two years. There is a decrease in forest cover and an increase in forest patches, an indication that there is fragmentation and loss. The number of patches were also analysed to ascertain whether fragmentation is increasing or not. According to Weins (1994), an increase in the number of forest patches is an indicator of fragmentation processes taking place. Figure 5 shows the differences in estimated number of patches between the two years.

It is shown that there is a significant change ($p>0.05$) in the estimated number of patches between the two years. In 1989, 5070 forest patches were observed in the ward. The number increased to about 8013 in 2003. The estimations confirm the views of the respondents in the area who attested to the view that there is an increase in forest fragmentation and habitat loss. Figure 6 shows the views of the respondents which confirm findings drawn from image analysis.

It is shown that the greater percentage (92%) of the respondents concurs with the fact that fragmentation and loss of forest is taking place in the area. The respondents revealed that construction of roads and clearance of forests for fields as well as human settlement and grazing are the prime causes of the fragmentation and loss in habitats.

A decrease in forest patch size is an indicator that fragmentation and loss is taking place (Sole et al., 2004). Analysis of patch size in ward 11 shows that fragmentation and loss are taking place. The mean patch size has changed between the two years. Figure 7 shows the statistical differences in patch size between the two years.

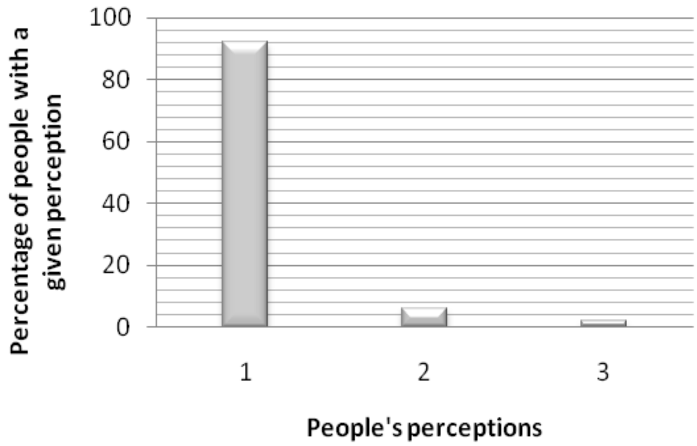

Figure 6. Perceptions about habitat fragmentation and loss in Chikombedzi area. 1) Habitat has been fragmented and lost 2) Habitat has been fragmented and not lost 3) Habitat has been lost but not fragmented.

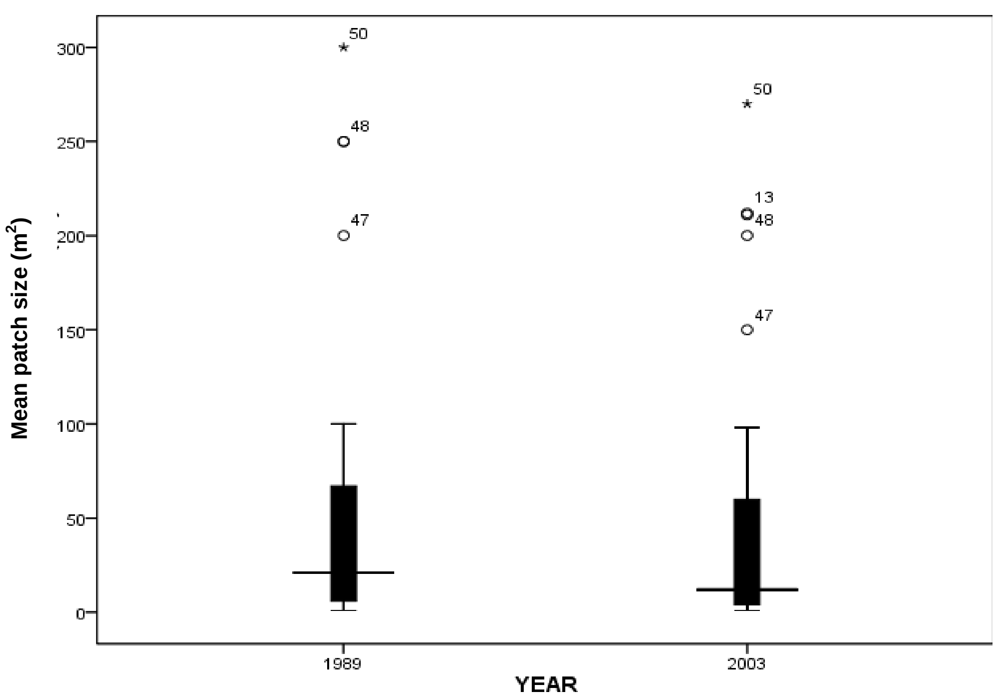

Figure 7. Forest patch size in 1989 and 2003 in ward 11, Chikombedzi area.

As shown in Figure 7, there is a significant ($p=0.002$, $\alpha=0.05$) difference between mean forest patch size in 1989 and 2003. In 1989 the mean patch size was 49.2 m^2 while that of 2003 was 42.74 m^2. Respondents also highlighted that there are significant changes in the size of forest patches in the area owing to multifarious human activities including veld fires, expansion of crop land, fuel wood harvesting and construction.

The total area for three main land uses in the area was also calculated and compared between the two years. Table 1 shows the differences in calculated croplands, forest and grassland area between the two years. In 1989 the area covered by forest habitat was 32.47% and in 2003 the habitat had changed to 31.69%. This shows that forest has been reduced in size over the 14 year period.

Some ecological changes are statistically insignificant but environmentally significant. The differences observed as shown in Table 1 are statistically insignificant but

Table 1. Cropland, forest and grassland area changes between 1989 and 2003.

Land cover type	1989		2003		Changes between 1989 and 2003	
	Area (km^2)	Percentage land cover	Area (km^2)	Percentage land cover	Difference in area	Percentage difference
Croplands	95.64	27.3	68.07	19.04	27.57	-8.26
Forest	113.75	32.47	113.29	31.69	0.46	-0.78
Grassland	140.91	40.23	176.19	49.27	-35.28	9.04

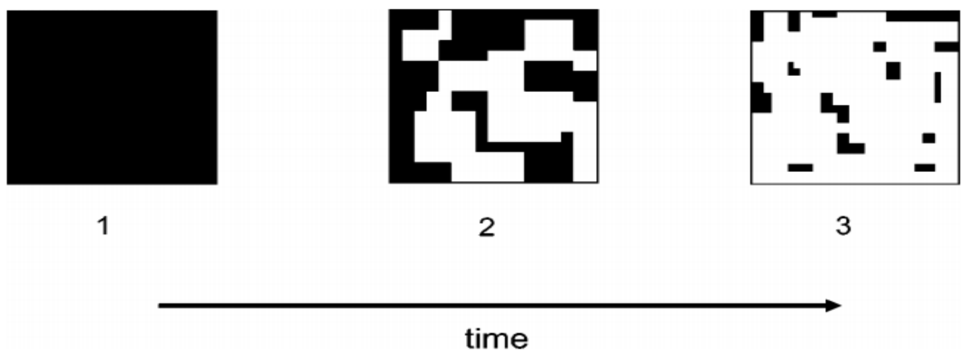

Figure 8. The process of fragmentation and loss of habitat.

environmentally significant because the slight change in land cover results in significant changes in species composition, richness and other ecosystem interactions.

DISCUSSION

In this paper, we analysed images and it was shown that there is a decline in forest area. Forest area declined from 32.47% of the total land area of the ward in 1989 to 31.69% in 2003. There is also evidence of an increase in forest patches, an indicator of fragmentation occurrence. This decrease in forest cover and increase in forest fragmentation has been confirmed by people resident in the ward for more than 25 years. The decrease in land under forests implies a change in species evenness and richness (Mcletchie, 2002; Alonso, 2004). As the area under forests decreases, the number of small vegetative species increases (Chapungu and Yekeye, 2013). However, although there is an increase in species richness, the size of the species in height and diameter at breast height has significantly decreased. This is mainly because deforestation, which has been highlighted as the key factor of fragmentation and loss, mainly affects species of larger sizes as they are targeted due to their socio economic benefits. This encourages growth of small graminae and herbaceous species which are smaller in size both in height and diameter.

The changes in forest cover confirm the views of the respondents that the rate of deforestation is increasing as the forests are a source of fuel wood for the inhabitants in the area. Moreover, agricultural land clearing activities have significantly changed land use patterns where woodland area has been transformed into shrubland mostly used for grazing purposes. This confirms Lord and Norton (1990)'s contention that agricultural activities play a critical role in habitat fragmentation, which consequently contribute to the changes in species evenness and richness.

Agricultural activities have influenced fragmentation and loss of forest habitat. However, due to scarcity and unreliability of rainfall, crop production has declined and most land has been left fallow resulting in growth of grasses and bushes. There is also evidence that some vegetative species have gone extinct. Local people confirmed that there are some vegetative species which became extinct in the area due to the fragmentation and loss process. When native vegetation is cleared (usually for agriculture or other kinds of intensive exploitation) habitats which were once continuous become divided into separate fragments (Figure 8) (Hanski, 1999; Pimm, 1991). After intensive clearing, the separate fragments tend to be very small islands isolated from each other by cropland and pasture.

Fragmentation and loss of habitat are recognized as the greatest existing threat to biodiversity. Such forest fragmentation and loss as illustrated in Figure 8 shows that Chikombedzi district could be facing serious challenges with regards the loss of forests due to a combination of natural disasters in the form of droughts and human activities in the form of expansion of agricultural area, settlement and other developmental activities.

Conclusions

In this study, we concluded that using a multi-method design provides a confirmatory dimension to research results. This is useful in verifying results obtained from satellite image analysis or from other qualitative methods. Using this design, we conclude that there is a decrease in forest cover and an increase in forest patches, an indication that there is habitat fragmentation and loss. The key factor of this fragmentation and loss is deforestation which is perpetuated for several reasons including human settlement, agriculture and infrastructural development. Natural phenomena such as droughts have exacerbated the ecological impact. The vegetative species mostly affected are *Mopani* and *Mutsviri*. These tree species are mainly prone to deforestation because of their socio economic value and multi-purpose functions.

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