The present conservation status of *Juniperus* forests in the South Ethiopian Endemic Bird Area

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Key words: Ethiopia, *Juniperus procera* Hochst, forest, habitat change, Landsat, satellite imagery

Running title: Status of south Ethiopian *Juniperus* forests

Abstract
Field survey data and Landsat satellite imagery were used to evaluate the conservation status of two *Juniperus* forests (Mankubsa and Arero) in the south Ethiopian Endemic Bird Area. Forest cover and dense woodland decreased in both areas between 1986 and 2002, but rates of habitat change and human impact were greater at Mankubsa than at Arero. We suggest that at Mankubsa increased grazing pressure, agricultural expansion, commercial fuelwood and timber exploitation are threatening forest persistence, while most of the degradation at Arero is due to the grazing of domestic animals. Conservation efforts should focus on creating tree plantations and improving forest resource use efficiency at Mankubsa, while at Arero better results could be obtained by improving pasture quality in the habitats surrounding the forest.

Introduction
The highlands of South Ethiopia are well known as an internationally important Endemic Bird Area (EBA), containing five restricted-range bird species (Stattersfield *et al.* 1998). Although the available information (Stattersfield *et al.*, 1998; EWNHS, 1996; BirdLife International, 2000) suggests that the conservation status of the EBA is poor, due to increasing levels of human activity and habitat loss, no recent information is available to quantify the likely trend of human impact in the area.

In this paper we focus on the *Juniperus* forest of the South Ethiopian EBA. We assess its present conservation status on the basis of field work carried out in early 2003. We also analyse satellite imagery that allows a more precise assessment of forest cover changes over a 16 year (1986-2002) time span. Finally, we suggest actions and priorities for the conservation of this habitat.

Methods
We focused on two forests already well known for their high conservation value and recognised as Important Bird Areas (EWNHS, 1996; Fishpool & Evans, 2001): Arero

(4°50'N 38°50'E; visited from 20 to 23 February 2003) and Mankubsa-Walenso (5°15'N 39°35'E; visited from 11 to 13 February 2003).

The forests grow at altitudes of 1400-1800 m, with rainfall estimated to be 700-800 mm / year, mostly restricted to March-May and September-October (EWNHS, 1996). Although Mankubsa is lower (about 2-300 m), and has probably always been much smaller than Arero (Fig. 1), it is likely that vegetation structure and flora of the two areas did not differ much before human intervention, with *Juniperus procera* Hochst. ex Endl. and *Olea europaea* L. being the two most common tree species, forming canopies 20-30 m high (Haugen, 1992). Heavy exploitation of *Juniperus* and *Olea* has led to almost complete disappearance of these species from Mankubsa in recent years. At least two globally-threatened bird species (Prince Ruspoli's turaco *Tauraco ruspolii* Salvadori and Salvadori's serin *Serinus xantholaema* Salvadori) are found in the forests and adjoining habitats (EWNHS, 1996).

Patterns of human settlement are different in the two areas (Fig. 1). At Mankubsa, most of the human population lives in or around the large town of Neghele Borana, about 5 km north of the forest. At Arero several small villages are distributed all around the forest. Road access is easier at Mankubsa, which is crossed by an all-weather road, while only small dry-season tracks are found at Arero.

Field survey

We collected field data from a total of 102 sample sites (68 at Arero, 34 at Mankubsa). These were sited at 250 m intervals along transects within the area classified as "forest" in 1:50,000 maps (EMA, 1989). At each site, within a radius of 25 m, we recorded the following variables: (1) presence of *Juniperus procera* trees with height > 3 m (2) percentage vegetation cover in four height strata (0-1, 1-3, 3-8 and > 8 m) (3) canopy height (average of three readings with a telemeter) (4) grazing intensity (on a 4-level scale ranging from no to high grazing). Within a radius of 10 m, we also estimated (1) tree density, by counting the number of trees in three size-classes (0-5, 5-20 and > 20 cm diameter at breast height) and (2) human impact, by counting the number of woody stems that had been cut or showed scars or other signs of human activity.

Since the variables, in spite of various transformations, could not attain normality, all analyses were done with non-parametric statistics.

Satellite imagery analysis

Analyses were based on images from Landsat Thematic Mapper (January 1986) and Enhanced Thematic Mapper Plus (January and February 2002). Images were resampled to a pixel dimension of 28.5 m, georeferenced to 1:50,000 maps produced by EMA (1989) and checked with GPS in the field. The spatial precision of georeferenced images was approximately one pixel with respect to maps and field measurements and within one pixel between different images.

The analyses were based on two windows of 24 x 37.5 km (Arero) and 11 x 16 km (Mankubsa). These windows included the total extent of the habitat classified as "forest" in 1:50,000 maps (EMA, 1989). Images were displayed in multispectral combination of the bands 4-5-3 and visually interpreted based on habitat descriptions recorded at 75 GPS fixes taken in the field by the remote sensing expert (FG). We distinguished four land cover types: forest (corresponding to mapping unit 19a of White, 1983), dense woodland (mapping unit 38 of White, 1983), light woodland (mapping unit 42 of White, 1983), open habitats (this category includes grasslands, settlements and cultivation). Classification accuracy of the 2002 images was estimated to 81% by comparison with the 102 sample sites that were independently assessed during the field survey.

We also evaluated land cover changes between 1986 and 2002. However, crude estimates of surface loss do not give a complete picture of the conservation status of a habitat, since progressive degradation, through selective logging, fires, and grazing, may have important effects on habitat quality and its suitability to species of conservation concern (Robinson & Robinson, 1999; Forman, 1997; Pullin, 2002). We therefore evaluated levels of habitat degradation by calculating, within the pixels classified as "forest" in the 1986 satellite images, a Normalized Difference Vegetation Index (NDVI: Tucker, 1979) according to the following formula:

$$(B4-B3) / (B4+B3)$$

where B4 is the Near Infrared band of the Landsat sensor (wavelenght 0.75 to 0.90 μm) and B3 is the red band (0.63 to 0.690 μm). The principle behind NDVI is that leaf pigments strongly absorb the incoming radiation in the red region of the electromagnetic spectrum, whereas the spongy mesophyll of the leaves causes considerable reflectance in the near-infrared. As a result, vigorously growing healthy vegetation has low red reflectance and high near-infrared reflectance, and hence higher NDVI values.

To confirm that NDVI could be a useful index of forest quality in our survey area, we used a Principal Component Analysis (PCA) to summarise vegetation structure data (percentage vegetation cover, canopy height and tree density) collected in the 102 sample sites surveyed in the field. PCA scores were regressed on mean NDVI in a radius of 57 m (i.e., two pixels) around the sample point. We then used Kruskal-Wallis test (non-parametric equivalent of one-way ANOVA) to compare NDVI between forests (Arero *versus* Mankubsa) and periods (1986 *versus* 2002) in a sample of 900 randomly extracted pixels within each forest. Finally, to find out if patterns of forest degradation could be related to human settlements, within the same two sets of 900 pixels, we regressed NDVI changes between 1986 and 2002 on the distance to the nearest town or village.

Results

Field survey of the forest structure

Arero and Mankubsa forests differed strongly in most of the vegetation structural variables. At Arero we found higher canopy, more cover of plants above 3 m in height and higher density of trees with diameters > 5 cm (Table 1). *Juniperus procera* was recorded in 66% of samples at Arero, but only in 24% at Mankubsa (Chi-squared tests, d.f. = 1; $p < 0.001$).

Variables describing human impact also differed significantly between the two sites. Grazing intensity was higher at Mankubsa (Fig. 2; Kolmogorov-Smirnov test, $p < 0.05$), where we also found a higher density of cut stems (Arero 147 ± 14 (SE) stems / ha; Mankubsa 326 ± 6 (SE) stems / ha; Mann-Whitney test, $U = 497$, $p < 0.001$)

Satellite imagery analysis

Forest cover decreased in both areas between 1986 and 2002, although percentage of cleared forest was much higher at Mankubsa than at Arero (Table 2; Fig. 1). Light woodland increased in both areas, but more markedly at Arero. An increase in open areas (mainly cultivated fields) was observed at Mankubsa, but not at Arero (Table 2), where, however, many small-sized fields were indistinguishable from light woodland in satellite imagery and could have been lumped with that class, leading to under-estimation of open areas.

PCA extracted two axes that together accounted for 60% of vegetation structural variation in the 102 sample sites. Canopy height, tree density and cover of trees higher than 3 m had positive loadings on PCA Axis 1 (Table 3), which can be considered an axis of increasing forest density. On the contrary, negative loadings of vegetation lower than 3 m on Axis 2

(Table 3) suggest that this axis mainly expressed decreasing undergrowth density. NDVI was positively related to PCA Axis 1 (equation: $y = 0.24x - 0.07$; $R = 0.48$; $p < 0.001$), but not to Axis 2 ($p > 0.05$). We conclude that NDVI successfully represents a gradient of increasing forest density (i.e, pixels with higher NDVI have higher, more closed canopies, and higher tree densities).

There were highly significant differences (Kruskal-Wallis test, $p < 0.001$) in NDVI between both forests and years. Values of Arero were higher than those of Mankubsa and those of 1986 higher than 2002 (Fig. 3).

NDVI change between 1986 and 2002 was negatively correlated to distance from the nearest human settlement in Arero forest (i.e., higher changes were found nearer to settlements), although the amount of explained variance was low (equation: $y= -2.8*10^{-6}x + 0.21$; $R^2 = 0.07$; $p = 0.038$). On the contrary, at Mankubsa there was a significant positive correlation between distance and the amount of NDVI variation (equation: $y= 3.3*10^{-6}x + 0.16$; $R^2 = 0.22$; $p < 0.001$), suggesting that in this area places furthest away from settled areas were those that suffered more degradation.

Discussion

Our survey provides the first quantitative estimates of human impact on a natural habitat in the South Ethiopian EBA. Our analyses suggest that the magnitude of habitat destruction is so high that it is unlikely that *Juniperus* forests will persist for long. We found that forest decreased by 8.7-39.4% in 16 years of time in the two areas. Furthermore, crude figures of the amount of habitat loss do not take in account the fact that the most of remaining forest shows signs of heavy degradation. Our data also demonstrate that there are important differences between the two areas in the patterns of land use and habitat degradation. This in turn has conservation implications.

During the last decades, exploitation of the forests has been steadily growing, but with different effects in the two areas. The percentage of totally cleared forest between 1986 and 2002 was higher at Mankubsa than at Arero, and the field survey showed that the remaining forest at Mankubsa had lower canopy height and lower tree density, as well as more signs of human exploitation. *Juniperus procera* was less common at Mankubsa, although *Juniperus* stumps were extremely abundant (LB, *pers. obs.*). Since *Juniperus procera* is one of the most valuable timber trees in Ethiopia (Bekele-Tesemma *et al.*, 1993), the scarcity of this species suggests that Mankubsa has been subjected to strong selective logging, which was made easier by the availability of a better road system and stimulated by the existence of a large town (Neghele Borena), whose inhabitants need large quantities of firewood and timber. By contrast, no (or little) commercial logging seems to occur in Arero forest, as no large town is found in the area and road access is more difficult.

Patterns of land use change also differed between the two areas. Light woodland strongly increased at Arero. Our field observations suggest that light woodland is dominated by various species of small thorny *Acacia* species such as *A. drepanolobium* Harms ex Sjöstedt and *A. bussei* Harms ex Sjöstedt that often increase in overgrazed areas (Pratt & Gwynne, 1977). It is likely that an increase in grazing pressure was the main driving force in land use change at Arero. Grazing of domestic animals occurs not only in woodland habitats, but also in the forest, where it seriously reduces forest tree regeneration, which appears to be very low, thus posing a threat to forest persistence. On the contrary, at Mankubsa there was an increase not only of light woodland, but also of open habitat (that included many cultivated fields), thus suggesting an increase not only of grazing pressure but also of agriculture.

NDVI was significantly lower at Mankubsa than at Arero both in 2002 and 1986. Since we found that the index was related to forest density (i.e., PCA axis 1), and that Mankubsa showed more human damage in 2002, we hypothesise that the lower NDVI of 1986 indicates that Mankubsa forest was already being more intensely exploited than Arero. More interestingly, we found a strong decrease of NDVI in both areas between 1986 and 2002. This suggests that severe habitat degradation occurred at both sites. The strong decrease of NDVI could in part be due to inter-year variation in rainfall, which obviously influences vegetation health. However, inter-year climatic fluctuations are not consistent with the patterns of spatial variation of NDVI change between 1986 and 2002, which was significantly correlated to the distance from human settlements. Spatial patterns of NDVI variation were opposite in the two forests, in Arero NDVI decreased more markedly near settlements, while at Mankubsa the highest rates of change were found in areas furthest from Neghele. We hypothesise that this difference can be explained by the different patterns of human settlement and economic activity in the two areas. At Arero, a large part of the human population is nomadic and lives in small villages located all around the forest, or even in tiny clusters of huts that are inhabited only during the dry season, when the forest is an important source of water and pasture. Access to the forest occurs from all directions, and forest use increases towards the edges, where the villages are located. However, the small amount of variance explained by the regression between NDVI change and distance to villages suggests that forest utilisation is quite even, and that very few areas in Arero forest are outside the range of nomadic pastoralists.

On the other hand, at Mankubsa, most people live in or around Neghele, which has been a regional centre since the beginning of the last century, and attracts a constant flow of fuelwood and timber to satisfy the needs of a mainly resident population. Forest utilisation has been strong in the area for a long time, and in the late 1980's there was already concern for the conservation of Mankubsa (Haugen, 1992). We hypothesise that, by 1986, most of the northern part of the forest (i.e., that nearest to the town), had already been logged heavily, while areas located more southwards still had some timber left, as one of us noted in 1995 (Borghesio, 1997). After 1986, the need for timber and fuelwood led to the exploitation of the remaining patches of forest, in the southern part of the area. During our 2003 visit almost all large-sized trees had been removed, effectively transforming the forest into a dense bush with only scattered trees of low commercial value (such as *Euclea schimperi* Hiern, *Pistacia aethiopica* Kokwaro, *Haplocoelum foliolosum* (Hiern) Bullock and *Acacia brevispica* Harms).

The main findings of our survey are: (1) the present conservation status of the *Juniperus* forests of the South Ethiopian EBA is critical, and Mankubsa shows more degradation than Arero (2) damage at Arero stems mainly from seasonal use by pastoral nomadic people (and from wildfires, that were not assessed by this survey), but at Mankubsa, besides the grazing of domestic animals, there is a strong commercial exploitation of fuelwood and timber.

From a practical conservation point of view, we believe that Mankubsa is now no longer an issue in the field of conservation, but rather one of environmental restoration. Although the endangered Prince Ruspoli's turaco still persisted in the area in 2003, its habitat has been severely degradated. The near-total removal of *Juniperus procera* is likely to have major effects on the ecosystem, because its large size and importance as a resource for frugivores make it a keystone species. We feel that most of the biodiversity value of Mankubsa has probably already been lost. With the disappearance of the forest, fuelwood is now in short supply in Neghele, as shown by its increasing price (Neghele Rural Land Administration Office, *pers. comm*). Reafforestation programs should therefore be given a high priority in the area, and *Juniperus procera* should be chosen in preference to introduced species such as *Eucalyptus* spp., since local people usually avoid using these trees, which are said to provide low-quality wood (Neghele Rural Land Administration Office, *pers. comm*). Promotion of more efficient use of resources, such as high-efficiency stoves (Habermehl, 1999), could also prove effective at Mankubsa.

At Arero, on the other hand, true forest is still extensive, and a substantial number of forest-dependent species of flora and fauna are found in the area, so that it retains high conservation value, as well as an important role as a water catchment area. The exploitation of Arero forest is now mainly a subsistence one, as the lack of good roads and the lower population density still protect the forest from heavy commercial logging. Most local people are nomadic or semi-nomadic pastoralists who use the forest seasonally, and collect only wood products for their personal use. Since these products are free of charge, the local people probably have no interest in making their lifestyles more sustainable. Neither high efficiency stoves nor tree plantations are likely to have any appeal for the human population in Arero. In this area, the most important conservation actions should probably be focused on lowering grazing pressure of domestic animals in the forest. One possibility would be to concentrate efforts on the large expanses of shrub-encroached open woodland that has greatly expanded in the area in recent times. Habitats dominated by dense thorny shrubs are one of the most important threats to pasture quality in Eastern Africa (Pratt & Gwynne, 1977), and the recovery of these areas (for instance by mechanical cutting of the shrubs) could increase pasture quality in open habitats, thus lowering grazing pressure in the forest.

Acknowledgements

We thank Tesfaye Hundessa (Ethiopian Wildlife Conservation Organisation), Alemayehu Erena (Oromya Region Rural Land & Natural Resources Authority) and Kinfe Abebe (Ethiopian Wildlife and Natural History Society) for helping us in obtaining research permits and organising the survey. Many thanks are also due to Akale Yemane for his help and to Andrea Borghesio, Aman Dadessa, Ketema Fufa, Daniele Rizzo, Omega Girmay, to our drivers and the local guides who participated in the field work. Without their help this survey could never have been accomplished.

This survey was entirely funded by Al Wabra Wildlife Preservation, Sheikh Saoud Bin Mohammad Bin Ali Al-Thani (Qatar), whose support we gratefully acknowledge. Simon Jensen and Sven Hammer gave us invaluable support and assistance throughout all the stages of the project.

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Table 1 Average (±SE) of eight vegetation structural variables in the two survey areas. Statistical differences were calculated with Mann-Whitney test.

Variable	Arero	Mankubsa	Difference
% cover (0-1 m stratum)	44.2 ± 3.0	45.3 ± 2.5	U = 1139; p = 0.90
% cover (1-3 m stratum)	34.5 ± 2.1	38.0 ± 1.8	U = 936; p = 0.12
% cover (3-8 m stratum)	40.5 ± 2.5	17.1 ± 1.6	U = 440.5; p < 0.001
% cover (> 8 m stratum)	10.6 ± 1.3	2.7 ± 0.8	U = 562; p < 0.001
Density of trees <5cm (inds./ha)	616.8 ± 111.6	341.0 ± 48.4	U = 998; p = 0.26
Density of trees 5-20 cm (inds./ha)	333.9 ± 50.3	136.8 ± 22.9	U = 635.5; p < 0.001
Density of trees >20cm (inds./ha)	110.5 ± 16.7	29.0 ± 9.4	U = 529.5; p < 0.001
Average canopy height (m)	9.0 ± 1.1	4.5 ± 0.3	U = 635.5; p < 0.001

Table 2 Area (hectares) occupied by different habitat classes in the two survey areas in 1986 and 2002

	Arero			Mankubsa		
	1986	**2002**	**% variation**	**1986**	**2002**	**% variation**
Forest	8,590	7,839	-8.7	1,253	760	-39.4
Dense woodland	58,701	51,609	-12.1	9,246	8,081	-12.6
Light woodland	14,574	23,327	+60.0	4,198	4,735	+12.8
Open habitats	8,649	7,739	-10.5	2,878	3,999	+39.0

Table 3 PCA loadings of the 8 vegetation structure variables recorded in the 102 vegetation sample sites. The table also shows eigenvalues and the percentage of variance explained by each axis.

Vegetation variables	Axis 1	Axis 2
% cover (0-1m)	-0.24	-0.47
% cover (1-3m)	0.02	-0.60
% cover (3-8m)	0.42	-0.35
% cover (>8m)	0.34	-0.12
no trees (0-5cm)	0.33	-0.40
no trees (5-20cm)	0.40	0.05
no trees (>20cm)	0.44	0.14
canopy height	0.43	0.33
Eigenvalues	3.28	1.53
% variance explained	41.0	19.1

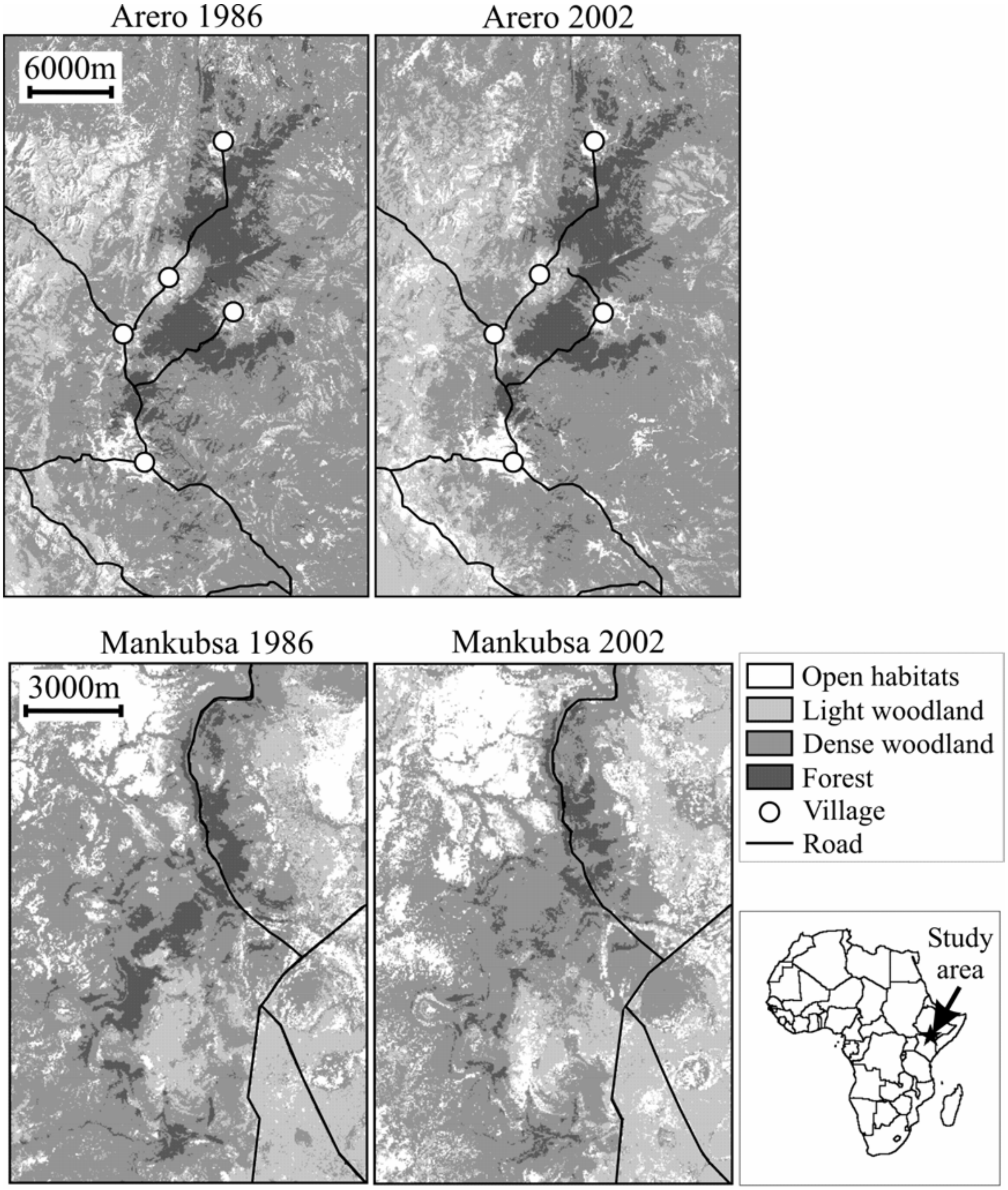

Fig 1 Map of the study areas, showing the main settled areas, roads and the extent of four habitat classes in 1986 and 2002. The large town of Neghele (outside of the image) is located approximately 2 km North of the survey area at Mankubsa.

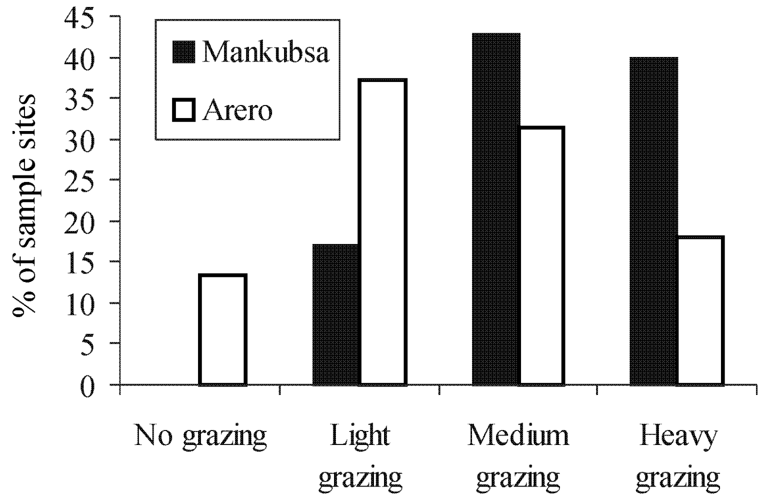

Fig 2 Per cent of sample sites in the four classes of grazing intensity in the two survey areas.

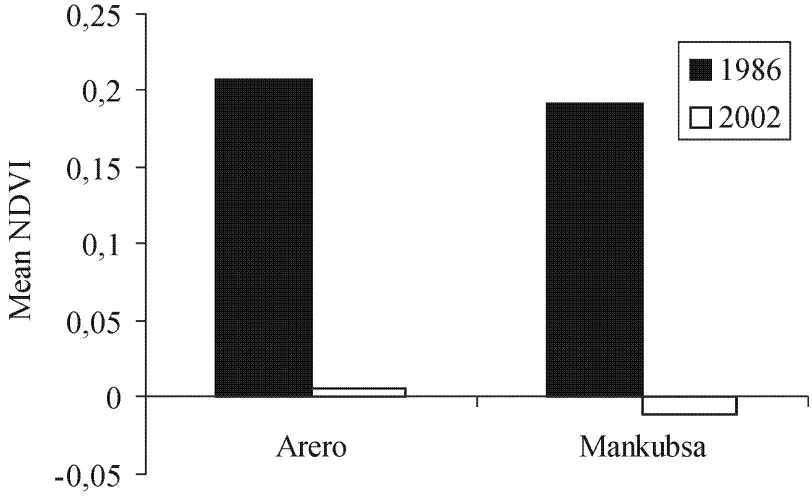

Fig 3 Variation of the mean NDVI at Arero and Mankubsa forests between 1986 and 2002 (sample size: 900 randomly selected pixels in each forest).