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Effects of anthropogenic fire history on savanna vegetation in northeastern Namibia

Asser Sheuyange[a], Gufu Oba[a,*], Robert B. Weladji[b]

[a]Noragric, Department of International Environment and Development Studies, Norwegian University of Life Sciences, P.O. Box 5003, Parkgarden Room 209, N-1432 Ås, Norway

[b]Department of Animal and Aquacultural Sciences, Norwegian University of Sciences, Ås, Norway

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Abstract

Anthropogenic fires in Africa are an ancient form of environmental disturbance, which probably have shaped the savanna vegetation more than any other human induced disturbance. Despite anthropogenic fires having played a significant role in savanna management by herders, previous ecological research did not incorporate the traditional knowledge of anthropogenic fire history. This paper integrates ecological data and anthropogenic fire history, as reconstructed by herders, to assess landscape and regional level vegetation change in northeastern Namibia. We investigated effects of fire frequency (i.e. <5, 5–10 and >10 years) to understand changes in vegetation cover, life form species richness and savanna conditions (defined as a ratio of shrub cover to herbaceous cover). Additionally, we analysed trends in the vegetation variables between different fire histories at the landscape and regional scales. Shrub cover was negatively correlated to herbaceous cover and herbaceous species richness. The findings showed that bush cover homogenisation at landscape and regional scales may suggest that the problem of bush encroachment was widespread. Frequent fires reduced shrub cover temporarily and promoted herbaceous cover. The effects on tree cover were less dramatic. The response to fire history was scale-independent for shrub, herbaceous and tree cover, but scale-dependent for the richness of grass and tree life forms. Fire history, and not grazing pressure, improved savanna conditions. The findings emphasise the need to assess effects of anthropogenic fires on vegetation change before introducing new fire management policies in savanna ecosystems of northeastern Namibia.

Keywords: Anthropogenic fires; Bush encroachment; Indigenous knowledge of herders; Fire history; Namibia; Savanna; Scale dependence; Species richness; Vegetation trends

1. Introduction

Africa is often referred to as a 'fire continent' (Trollope and Trollope, 1996) because of widespread anthropogenic fires (i.e. fire associated with anthropogenic land use) that annually burn the savanna vegetation (Mbow et al., 2000; Reid et al., 2000; Laris, 2002; Danthu et al., 2003). In the savannas of southern Africa, where anthropogenic fires are frequent (Scholes and Archer, 1997), the *San* hunter–gatherers in the Kalahari region used savanna burning for manipulating vegetation to attract the animals they hunt (Sheuyange, 2002). Following the introduction of traditional pastoral production to the southern region of Africa by 1800 BP (Smith, 1993), anthropogenic fires probably became more frequent, playing an increasingly important role in the development of vegetation communities (Werger, 1983). Effects depend on the intensity and frequency of fires (Scholes and Archer, 1997) which in turn is a function of the physical characteristics of the fuel load (Oba, 1990). In the absence of periodic fires, the vegetation shifts from herbaceous dominance towards a thickening of bush cover (Trollope, 1982; Knoop and Walker, 1985; Oba et al., 2000a) might be linked to the intensity of grazing pressure (Guevara et al., 1999; Weber et al., 2000).

Despite anthropogenic fires accounting for over 70% of the annual fires in African savannas (Van Wilgen et al., 1990), the roles anthropogenic fires play in vegetation dynamics are poorly documented. Previously, researchers

* Corresponding author. Tel.: +47 6494 9816; fax: +47 6496 5201.
E-mail address: gufu.oba@umb.no (G. Oba).

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predominantly evaluated effects of prescribed burning from the perspectives of changes in vegetation composition and environmental impacts (e.g. the volume edited by Goldammer (1990)). Researchers did not incorporate the traditional herders' knowledge about anthropogenic fires to assess landscape level vegetation change for managing savanna ecosystems. However, a recent focus on interdisciplinary research involving ecologists and herders (Bollig and Schulte, 1999; Hudak, 1999; Sullivan, 2002; Fernandez-Gimenez, 2000; Oba et al., 2000a; Oba and Kotile, 2001) showed that the integration of ecological and indigenous environmental knowledge (Berkes et al., 2000) would yield more information on the dynamics of savanna ecosystems and the response to management than using ecological methods alone. Herders are knowledgeable about fire history (Mistry, 1998), which is defined in terms of different fire return intervals (the intervals expressed in years since the last fire events) to the same landscape (Cary and Morrison, 1995).

Anthropogenic fires are managed at landscape levels. Herders classify landscapes using soils, vegetation and history of land use (Oba et al., 2000a; Oba and Kotile, 2001). Additionally, herders consider landscapes as grazing resources (Coppilillo, 2000; Oba et al., 2000a) and associate individual landscapes with personal experiences (Oba, 2001). Moreover, herders are knowledgeable about the status of vegetation at landscape scales in terms of stages of recovery from previous fire burns (Romme, 1982) compared to the unburned patches. As long as occurrence of anthropogenic fires is random, therefore, fire histories could be used to assess processes of vegetation change (Ludwig et al., 2000) between fire events reflecting landscape scale and regional scale changes. A coarse scale response reflects geographical variability in response to fire history (Mckenzie et al., 2000) and synchronised environmental factors such as drought (Brown et al., 2001).

The assessments of the effects of fire history on vegetation can be integrated into herders' knowledge of fire history. The information provided by herders is in terms of presence or absence of fires as opposed to fire intensity or the sizes of burns. The indirect evidence for assessing impacts of anthropogenic fires could be deduced from the vegetation cover, species richness as well as savanna conditions (Henderson and Keith, 2002). In this article, we defined savanna condition as the ratio of shrub cover to herbaceous cover.

We integrated the herder knowledge with ecological methods to investigate effects of anthropogenic fires and their interaction with grazing pressure on bush and herbaceous layer across landscape and regional scales and at temporal scales (i.e. in terms of fire history) in northeastern Namibia. The objectives of the study were: (1) To assess how fire history varied across different landscape associations. (2) To understand the correlation between bush cover, and herbaceous and tree cover and richness of plant life forms (i.e. herbs, trees and grasses). (3) To analyse the roles anthropogenic fires and grazing pressure played in changing (a) vegetation cover, (b) richness of plant life forms, (c) savanna conditions, and (d) trends in relation to fire history.

2. Study area

The study was conducted in northeastern Namibia. The region is semi-arid with mean annual rainfall ranging from 500 to 600 mm per annum. Rainfall is expected between March/April and October/November. Droughts lasting for several years and frosts that stress the environment occur as stochastic events (Byers, 1997). Landforms are predominantly the Kalahari sand dune remnants. There is an association between the types of soils and vegetation (Table 1). The vegetation is comprised of grass-woodland, bushland and woodland. Grass-woodland was comprised of herbaceous cover and grass under storey and sparse tree

Table 1
Indigenous classifications of landscape associations by the Owambo-pastoralists

Associations	Descriptions
Etunu-Ongoya	The landscape associations have varied soil types. The soils varied from reddish-grey to red loam sands and dark grey to reddish loamy sand. The name *Ongoya* refers to landscapes with dense thickets. The vegetation is dominated by *Dicrostachys cinerea*, *Baikiaea plujuga* and *Croton* sp. in the tree layer, while *Combretum apiculatum*, *Combretum collinum*, *Combretum gratissimus*, and *Terminalia sericea* and *Baphia masaiensis* made up the shrub layer. The grass layer is dominated by *Urochloa brachyura*, *Digataria eriantha*, *Eragrostis trichophora*, with *Brachiaria nigropedata* occurring in less grazed areas.
Ekango-Ombuwa	Clay pans surrounded by dense woodland characterise this landscape association. The soils are blackish grey clay and in *Ombuwa* the soils are dark grey loamy sand mixed with patches of limestone. There is shallow duricrust in the soil profile (Verlinden and Dayot, 1999). The woody vegetation on the edges of the pans is dominated by *C. hereense*, *Dicrostachys cinera*, *Peltophorum africanum*, *Acacia erioloba*, *Terminalia sericea*, *Ozoroa insignis*, *Rhus tenuinervis* and *Ziziphus mucronata*, serve as indicator species for the landscape association. The grass layer is diverse comprising *Cynodon dactylon*, *Eragrostis trichophora*, *Eragrostis holubii*, *Eragrostis* sp. *Aristida adscencioninis*, *Brachiaria nigropedata*, and *Schmidtia pappophoroides*.
Ehenga-Omufitu	The wooded landscape association comprised fossilised sand dunes and is the most common landscape associations in Eastern Ohangwena region. The main features are wooded bushland with grey sandy soils. The shrub layer is dominated by *Guibourtia coleosperma*, *Strychnos pungens*, *Brachiaria plurijuga*, *Pterocarpus angalensis*, *Burkea africana*, *Terminalia sericea* and *Shiniophyton ratanenii*. The herbaceous layer is dominated by *Aristida adscencioninis*, *Brachiaria nigropedata*, *Eragrostis trichophora* and *Schmidtia pappophoroides* and the grass by *Aristida stpioides*, *Aristida congesta* and *Pogonarthria fleckii*.

over storey. Pure grasslands are rare in the study area (Sheuyange, 2002). Landscape elevations in general vary from 1100 to 1112 m. The landscapes are the products of human activities. The human population of northeastern Namibia is estimated at about 21,000 (Ministry of Agriculture, Water and Rural Development, 2002, unpubl.). The Owambo agro-pastoralists engage mostly in livestock husbandry and some cultivation. Cattle and goats are grazed on communal pastures (Sheuyange, 2002). The pastoralists periodically conduct burning to enhance sprouts from trees and shrubs and regeneration of herbaceous vegetation to improve livestock feed quality. In the semi-arid region of northeastern Namibia natural fires induced by lighting are uncommon. In this article, all fires reported refer to those set by agro-pastoralists.

3. Methods

3.1. Indigenous landscape classifications and reconstruction of fire history

Sampling was done using road-transects at 2 km intervals and landscape assessments conducted at 97 stations across the region covering 4500 km^2. Following the Owambo-traditional systems of classifications the pastoralists described the landscapes using vegetation and soils and grouped them into three major landscape associations (*Etunu-Ongoya*, *Ekango-Ombuwa* and *Ehenga-Omufitu*) (Table 1). Traditional range scouts helped to reconstruct fire history for all surveyed landscape associations using the time scales of fire return intervals <5 (i.e. 0–5 years), 5–10 and >10 years since the last fire.

At each of the 97 sampling stations, a pair of 100 m transects were established. Plots were established at 20 m intervals to sample herbaceous and grass (1 m^2), shrub (25 m^2) and tree (625 m^2) cover. Because our interest was to understand variability of plant species richness at large scale (i.e. 4500 km^2), we preferred to express richness by life forms (i.e. numbers of the species of trees, shrubs, grasses and herbaceous species per unit area). Percentage cover of the vegetation layer (i.e. herbaceous and woody) was categorised, either as low (0–10%), moderate (10–20%) or high ($>20\%$). Grazing pressure for the current season was assessed on an ordinal scale as none (0%), light (0–25%), moderate (25–50%) and heavy ($<75\%$) based on observed signs of utilisation of plants compared to protected areas (Oba et al., 2001). Savanna conditions varied from poor ($>40\%$ bush cover), fair (20–40%), good (10–20%) to excellent ($<10\%$ bush cover). Trends in vegetation cover, richness of life forms and savanna conditions in relation to fire history were then determined (see below).

3.2. Analyses

We used linear models to assess the effect of fire history on vegetation cover and richness of plant life forms. Pearson's correlation was used to assess the correlation between: (i) tree, shrub and herbaceous cover as well as (ii) richness of tree, shrub and grass and herbaceous species and savanna conditions and fire history. Chi-square tests of independency were used to assess the degree of association between fire histories, grazing pressure, and landscape associations (FREQ procedure, SAS, 1999). Our tests were adjusted by way of the Mantel–Haenszel Chi-square (Agresti, 1996; SAS, 1999). We also used linear models to analyse the effects of fire history and grazing pressure interacting with landscape associations on (i) shrub cover, tree cover and total herbaceous cover, and (ii) species richness by plant life forms and (iii) savanna conditions. Despite landscape associations and fire history being correlated, we kept landscapes in the models when assessing the scale effect, and all interaction terms were tested. Interactions for the predictor grazing pressure in the full model were reported only when significant. In a separate set of analyses restricted to a single predictor variable (e.g. fire history), we assessed for the scaling effects. This was done both at the landscape scales (controlling for landscape associations) and regional scale (without controlling for the landscape associations). Trends in the differences between the means for fire return intervals <5 and 5–10 years and 5–10 and >10 years were determined for cover, richness of plant life forms and savanna conditions. The trends were analysed at individual landscape association levels and at the regional scales. A positive trend implied that the vegetation response variables were promoted, while a negative trend would suggest that the variables were reduced at $p<0.05$.

4. Results

4.1. Landscape associations and fire history

The landscape associations were dominated by *Ehenga-Omufitu* (51%) with *Etunu-Ongoya* (24%) and *Ekango-Ombuwa* (25%) occurring in comparable proportions. Linear model analysis showed that landscape associations had significant influence on herbaceous cover, shrub cover and tree cover (*F*-tests, all $p<0.05$, Table 2). Shrub cover had a significant correlation with herbaceous cover ($r=-0.29$, $p=0.003$) but not tree cover ($r=-0.11$, $p=0.28$). There was no correlation between tree cover and herbaceous cover ($r=0.11$, $p=0.25$). Anthropogenic fire frequency was variable between landscape associations (Fig. 1). In *Etunu-Ongoya* landscape associations, frequent fires <5 years were least represented. In *Ekango-Ombuwa*, the majority of the landscapes were in the category with fire history >10 years. In *Ehenga-Omufitu* about 45% of

Table 2
Results of linear models showing effects of fire history on vegetation cover (herbaceous, shrubs and tees) at landscape scale (controlling for landscape associations) and at regional scale (without controlling for the landscape associations)

Individual variable	Landscape scale			Regional scale		
	df	*F*	*p*	df	*F*	*p*
Herbaceous cover						
Landscape type	2	7.15	0.001			
Fire history	2	0.79	0.459	2	0.94	0.395
Landscape × fire history	4	3.51	0.010			
Shrub cover						
Landscape type	2	4.93	0.009			
Fire history	2	10.25	<0.001	2	12.88	<0.001
Landscape × fire history	4	4.16	0.004			
Tree cover						
Landscape type	2	3.26	0.043			
Fire history	2	0.16	0.854	2	0.42	0.655
Landscape × fire history	4	0.76	0.552			

the landscapes belonged to the fire history category <5 years (Fig. 1).

4.2. Effects of fire history and grazing pressure

We found no interactions between grazing pressure and landscape associations in terms of shrub cover, tree cover or herbaceous cover (*F*-tests, all $p > 0.05$). Herbaceous cover and shrub cover, through interactions with fire history, showed differences among landscape associations (*F*-tests, all $p < 0.05$; Table 2), while tree cover showed weaker interactions with fire history (Table 2). Chi-square analysis disclosed a significant association between fire history and landscape associations ($\chi^2 = 10.27$, df = 4, $p = 0.04$). Linear models of landscape associations and fire history (full models) showed significant interactions between fire history and herbaceous cover ($F_{24,77} = 2.02$, $p = 0.011$) and shrub cover ($F_{24,77} = 2.64$, $p < 0.001$), but not with tree cover ($F_{24,77} = 0.94$, $p = 0.55$). At the regional scales, anthropogenic fire history had significant impacts on shrub cover ($p < 0.05$), but not on herbaceous or tree cover (*F*-tests, all $p > 0.05$; Table 2), suggesting that the response by shrub cover was scale-independent.

4.3. Effects of fire on diversity of plant life forms

The richness of herbaceous vegetation (but not grass species richness), shrub and tree life forms showed high spatial variability at landscape scales (Table 3). Increased shrub species richness was followed by reduced tree species richness ($r = -0.205$, $p = 0.04$). Shrub species richness was not correlated with richness of herbaceous life forms ($r = -0.089$, $p = 0.38$). Conversely, the correlation between tree and herbaceous species richness was not significant ($r = 0.075$, $p = 0.45$). Furthermore, landscape associations and grazing pressure did not interact to influence grass species richness, herbaceous species richness or shrub species richness (*F*-tests, all $p > 0.05$). However, a weak link between shrub species richness and grazing pressure was probably mediated through fire history ($p = 0.06$).

At the landscape scale, fire history did not appear to influence herbaceous species richness and grass species richness, shrub species richness or tree species richness (*F*-tests, all $p > 0.05$; Table 3) compared to the regional scale where the effect of fire history was significant for grass and tree species richness (*F*-tests, all $p < 0.05$; Table 3). The evidence suggests that effects of fire history on grass and tree species richness were scale dependent. The interactions between fire history and landscape associations were significant for shrub species richness (Table 3), but not for herbaceous, tree and grass species richness (*F*-tests, all $p > 0.05$; Table 3). Similarly, in the full model, the shrub species richness showed interactions with fire history ($F_{24,77} = 2.49$, $p = 0.001$), while no interactions were detected for herbaceous ($F_{24,77} = 1.27$, $p = 0.21$), grass ($F_{24,77} = 1.24$, $p = 0.23$) or for tree species richness ($F_{24,77} = 1.48$, $p = 0.10$).

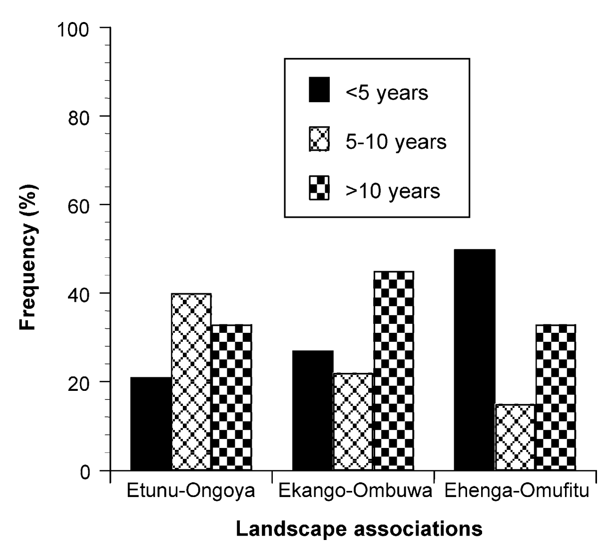

Fig. 1. Percentage of landscape associations by fire frequency class in Ohangwena region of Namibia.

Table 3
Results of linear models showing effects of fire history on plant species richness by life forms at landscape scale (controlling for landscape associations) and at regional scales (without controlling for the landscape associations)

Individual variable	Landscape scale			Regional scale		
	df	*F*	*p*	df	*F*	*p*
Herbaceous species richness						
Landscape type	2	3.69	0.029			
Fire history	2	0.54	0.582	2	1.56	0.215
Landscape × fire history	4	2.14	0.083			
Shrub species richness						
Landscape type	2	10.70	<0.001			
Fire history	2	0.63	0.535	2	1.70	0.187
Landscape × fire history	4	4.24	0.003			
Tree species richness						
Landscape type	2	5.86	0.004			
Fire history	2	1.81	0.169	2	3.34	0.040
Landscape × fire history	4	0.50	0.739			
Grass species richness						
Landscape type	2	0.05	0.953			
Fire history	2	1.47	0.236	2	3.20	0.045
Landscape × fire history	4	0.36	0.839			

4.4. Savanna conditions and trends

Savanna conditions were hugely influenced by landscape associations ($F_{24,77} = 9.54$, $p < 0.001$). The effect of fire history on savanna conditions was positive and significant at the landscape and the regional scales (*F*-tests, all $p < 0.001$), suggesting that the variation of savanna conditions was scale-independent. The trends of plant cover and richness of plant life forms against fire history at the landscape and regional scales did not disclose linear patterns (Fig. 2a–c). In response to fire return intervals >10 years, herbaceous cover showed a decline both in *Etunu-Ongoya* and *Ehenga-Omufitu* (Fig. 2a and c). In *Etunu-Ongoya*, the patterns showed declines in response to <5 and 5–10 year fire histories. The exception was in *Ekango-Ombuwa* (Fig. 2b) which showed an increase in shrub cover in response to frequent fires and a significant decrease ($p < 0.05$) in response to fire return intervals >10 years.

Frequent anthropogenic fires reduced shrub species richness, but positively influenced tree species richness, and herbaceous (except in *Ehenga-Omufitu*, Fig. 2d) and grass species richness (Fig. 2f). In *Ekango-Ombuwa* by contrast, frequent fires reduced herbaceous species richness compared to the shrub species richness, which did not appear to recover even after >10 years (Fig. 2e). In *Ehenga-Omufitu*, shrub species richness and herbaceous species richness showed recovery in response to the fire return intervals >10 years relative to the tree species richness. In the latter landscape association, grass species richness was substantially reduced by fire return intervals >10 years (Fig. 2f). At regional scale, frequent fires reduced shrub cover and shrub species richness but had no negative impact on the trends of tree and herbaceous cover, tree species richness, herbaceous species richness and grass species richness. Comparatively, in response to fire frequencies >10 years, tree cover, tree species richness and herbaceous species richness declined at the regional scales (Fig. 3a and b).

5. Discussion

5.1. Landscape associations and fire history

Greater variability in herbaceous cover across landscapes might suggest that the variability was probably more related to spatial rainfall variability, while tree cover reflected landscape heterogeneity (Rollins et al., 2002). The negative correlations between shrub and herbaceous cover confirmed the general concerns of herders, who perceived that increased shrub cover reduced herbaceous biomass production. The negative relationships between the shrub cover and tree cover might suggest that the two vegetation components were probably in competition. Increased shrub cover probably discouraged tree regeneration, while in landscapes with high tree cover the shrub-under storey was reduced. By comparison, the positive relationships between herbaceous cover and tree cover might suggest that the two vegetation components co-exist (Oba et al., 2000a).

Natural resource managers and conservationists in the past viewed anthropogenic fires as destructive elements to the vegetation communities. The general argument against anthropogenic fires is based on the premises that since fire spreads, intensity and frequency could not be controlled, and repeated burning might be damaging to fire sensitive plant communities. We showed that anthropogenic fires might be playing a positive role in savanna ecosystem dynamics. According to the Owambo herders, anthropogenic fires are planned and implemented to achieve specific management objectives. The narratives about rangeland burning by the herders are reported elsewhere (Sheuyange and Oba, unpubl.); suffice to add that herders are

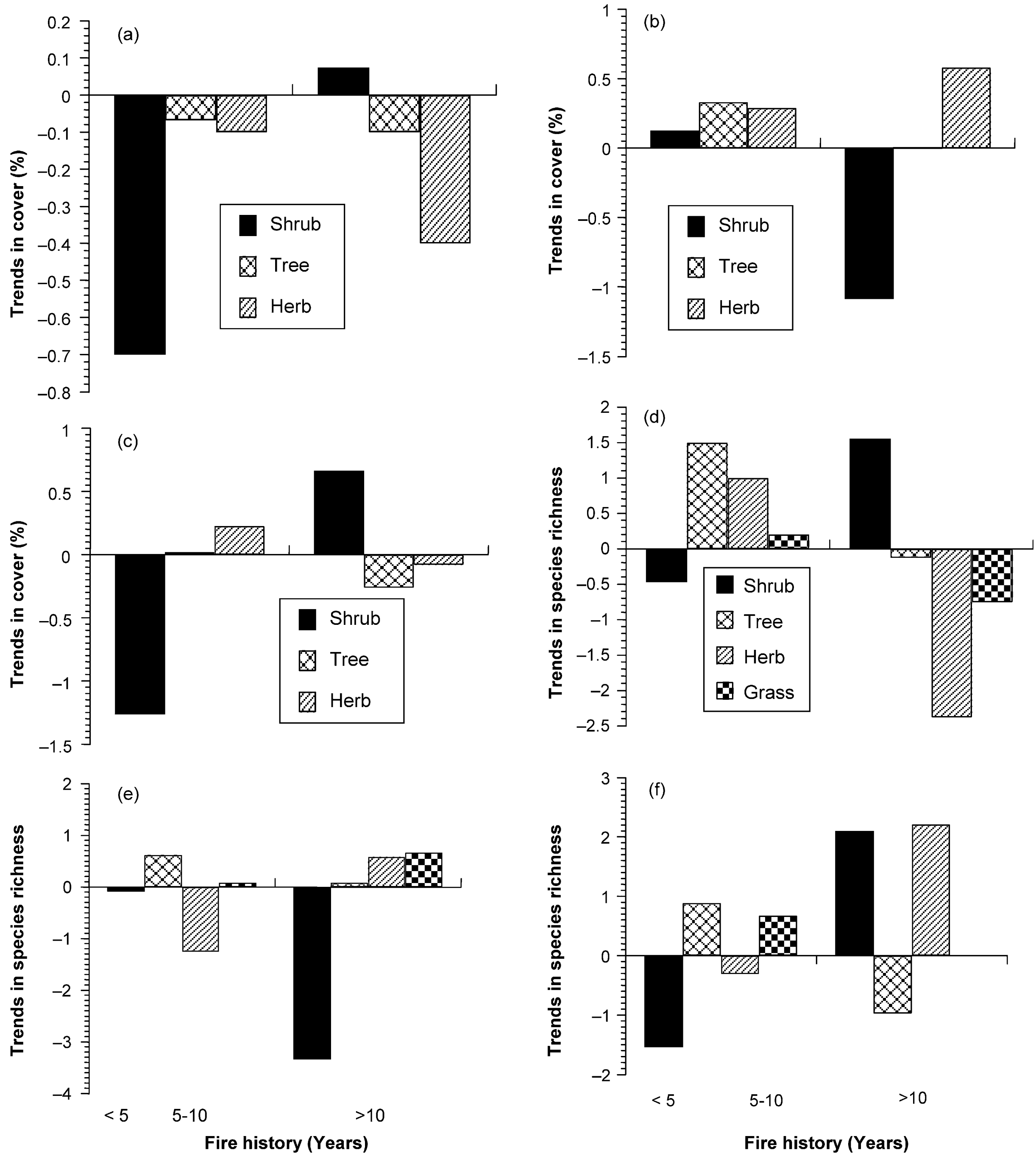

Fig. 2. Landscape level trends in shrub cover, tree cover and herbaceous cover in (a) *Etunu-Ongoya* (b), *Ekango-Ombuwa* and (c) *Ehenga-Omufitu* and shrub species richness, tree species richness, herbaceous species richness and grass species richness in (d) *Etunu-Ongoya,* (e) *Ekango-Ombuwa* and (f) *Ehenga-Omufitu* between fire history <5–10 and >10 years.

knowledgeable about the use of anthropogenic fires. A knowledgeable elder had this to say. '*Ofuka ei* (this landscape) is burned in August and September after the bushes have dried up. It is the herders who decide to burn…. We agree on places and the times to burn, because we know the needs of our cattle. We use fire cautiously and there are always many areas left unburned…. The aim of burning is to improve grazing for cattle' (Tatekulu J. Tawii, interviewed by Asser Sheuyange in July 2001). The burning of savanna vegetation as practiced by Owambo herders involved decisions related to more than grazing needs alone. Herders understood the conditions under which burning was ineffective. Another elder adds '…In places that are burned 2–4 years ago, the fire only scars the bushes …' (Tatekulu M. Shambongo, interviewed by Asser Sheunganye in July 2001). Traditionally, burning was practised for renewing pasture quality when woody and grass litter accumulated as fuel load (cf. Moritz, 2003).

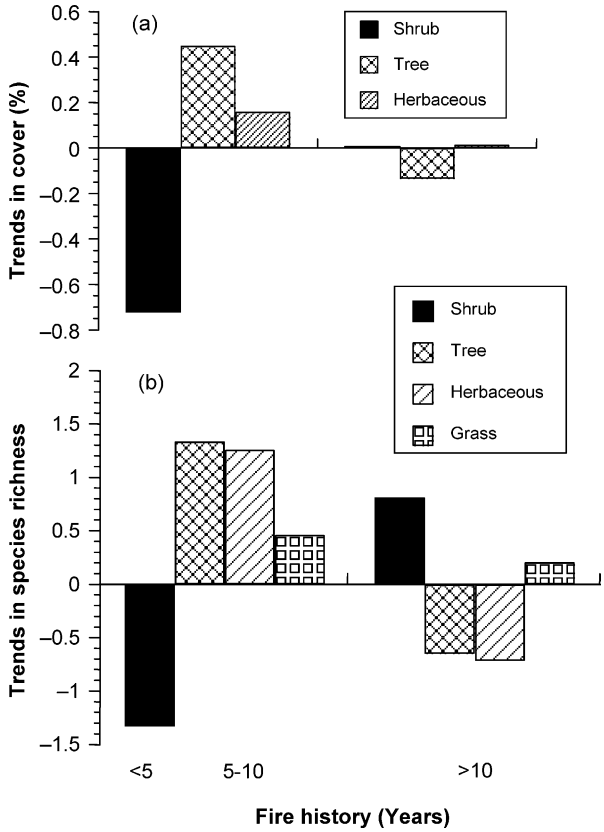

Fig. 3. Regional trends in (a) shrub cover, tree cover and herbaceous cover and (b) shrub species richness, tree species richness, herbaceous species richness and grass species richness reflecting mean differences between fire history <5 and 5–10 and >10 years.

Frequent fires (i.e. <5 years) were more common in some landscapes than in others, suggesting differences in ecological conditions as well as management of herders focused on particular landscape associations.

5.2. Effects of fire history and grazing pressure

Our findings confirmed the herders' perceptions that use of anthropogenic fires is to control bush cover and promote the herbaceous plant production. In the recently burned landscapes shrub cover was reduced and herbaceous cover and biomass and herbaceous species richness promoted. However, at regional scale, the shrub cover growth suggested that the majority of the landscapes were experiencing bush cover expansions. Growth of shrub cover probably reflected the interactions between climate variability (not shown) and fire frequency. We interpreted the correlative data on long-term trends cautiously (see also Jacobs and Schloeder (2002)) for the following two reasons. First, the spatial variation of vegetation cover was superimposed on fire history. Second, the relationship reflects the current situation (Trodd and Dougill, 1998) as opposed to the long-term trends. In the short-term, fire was less damaging to tree cover than bush cover, suggesting that this vegetation layer was more tolerant to anthropogenic fires than the bush layer, although it was likely that a greater fuel load by the shrubby plants would probably induce greater mortality among tree saplings (Oba, 1990). We did not observe strong links between anthropogenic fire history and grazing pressure (Lacey et al., 1982) and between grazing pressure and the vegetation cover (also see Roques et al. (2001) and Henderson and Keith (2002)). From our assessments, the current grazing pressure alone could not therefore be used to understand responses by the herbaceous and shrub cover.

5.3. Effects of fire history on diversity of plant life forms

Changes in plant species richness were explained more in terms of spatial variability (defined by landscape associations) than interactions with grazing pressure. Landscape associations had greater influence on the variations of herbaceous, shrub and tree species richness, but less so on the grass species richness. The evidence might suggest that the spatial variability of grass species richness was the product of rainfall variability (Oba et al., 2000b) rather than fire history alone (see below). The evidence that tree species richness was negatively correlated with shrub species richness might suggest that the two vegetation layers were competing (Walter, 1971).

Overall, grazing pressure alone did not appear to influence the spatial variability in herbaceous species richness or grass species richness. The variability was probably more influenced by rainfall than grazing and fire alone (Oba et al., 2000b). Moreover, fire history did not appear to influence the current grazing pressure, which was rather surprising, given the general viewpoint in the literature that grazing might reduce the herbaceous layer and promote bush cover (Jeltsch et al., 1997; Valone and Kelt, 1999). In the current study, therefore, the short-term grazing data could not be used to interpret the long-term changes in species diversity in response to grazing pressure. By comparison, the significant response by tree species richness to fire history at regional scales could be explained by ecosystem heterogeneity.

5.4. Effects of fire history on savanna conditions and trends

Generally, savanna conditions showed spatial variability while being positively influenced by frequent fires. The lack of correlation between savanna condition and tree cover suggests that this component of the vegetation was not responsible for the widespread problems of bush encroachment. We were interested in understanding how individual fire events controlled bush cover (Van Wijngaarden, 1985) and promoted herbaceous vegetation (Dublin et al., 1990).

Our results showed that plant cover and species richness responded differently to different fire history. The trends in relation to fire history were non-linear. Generally, more frequent fires (i.e. <5 years) compared to the less frequent fires (i.e. >10 years) produced negative trends in the shrub cover and shrub species richness, while the tree, herbaceous and grass species responded positively. Shrub cover recovered after fire return intervals >10 years (for the majority of the landscapes), showing an opposite trend to tree and herbaceous layers. Comparable patterns have also been reported (Cary and Morrison, 1995) showing that shorter fire return intervals reduced shrub cover and shrub species richness, while herbaceous species richness was promoted. Morrison et al. (1995) also found that fire frequency would account for the greater variability of shrub cover.

At the landscape scale, the patterns in response to fire history were different in *Ehanga-Ombuwa*. In this landscape association, bush cover increased following recent fire history but declined in response to the fire return intervals >10 years. According to herder informants, bushy plants invaded this particular landscape association about four decades ago. In the words of a knowledgeable elder '…Before, there were scattered trees in *Ekango-Ombuwa*. What you see all around us (referring to bushy thickets) was absent when I came to this place 40 years ago. …Now the entire area has turned into thickets, fire has lost its effects' (Tatekulu T. Nakale, interviewed by Asser Sheuyange in July 2001). But what was unclear is why the pattern of shrub mortality in this particular landscape was different from those of other landscape associations. Greater shrubby plant mortality, under the increased fire return intervals >10 years, is probably related to stochastic weather events (Sheuyange, 2002). The patterns at the regional scales confirmed that the vegetation responded differently to fire frequency, confirming the important roles anthropogenic fires played in the savanna ecosystem in northeastern Namibia.

6. Management implications

The evidence we present shows that incorporating indigenous ecological knowledge of herders into analysis of scaling effects of anthropogenic fires on savanna vegetation has important management implications (Mbow et al., 2000; Lykke, 2000). Firstly, herder knowledge can be used to identify individual landscapes and their geographical locations (Oba, 1994). Secondly, herder knowledge would improve the understanding of the long-term response of savanna vegetation to human induced fires (Mistry, 1998; Preece, 2002). Thirdly, herder knowledge would promote participation by local peoples for the management of fire prone savanna ecosystems. More importantly, given that anthropogenic fires contributed to the evolution of savannas (Trollope and Trollope, 1996) herder knowledge might provide useful information for formulating management policies (Giuliani and Chaloupka, 1997). It should however be appreciated that herder knowledge is based on various environmental and management indicators most of which were not considered. The knowledge of herders is appropriate for general information and that is why our ecological measurements were necessary to provide detailed and specific information on effects of fire history. Thus, as a basis for environmental monitoring, we consider indigenous knowledge of herders as adequate for ecologists to work with.

The herders associated range burning with positive outcomes in terms of reduced bush cover and increased fresh growth of vegetation for livestock grazing. From the study, therefore, we can deduce that the integration of herder knowledge with ecological methods for assessing impacts of anthropogenic fires could be applied at multiple scales (Mckenzie et al., 2000). However, from our data, it did not appear that herders deliberately used fire to manage biodiversity. Rather, we used the information to evaluate the impacts of fire periodicity on plant species richness to dispel the perception of conservationists that anthropogenic fires are detrimental to plant biodiversity. In our study, the landscapes with fire return intervals >10 years could serve as controls. The landscapes failed to disclose superior plant species richness to those that experienced more frequent fires. The patterns of vegetation change in terms of the richness of plant life forms in response to different fire history may therefore be used to manage vegetation at landscape and regional scales (Keeley, 2002). Proper understanding of the effects of anthropogenic fire history on vegetation change could be used for formulating fire management policies for savanna ecosystems in general.

7. Conclusion

Integration of indigenous knowledge for reconstructing fire history to determine effects at multiple scales was successfully used to investigate vegetation changes in northeastern Namibia. The landscape associations had varying fire history that reflected variability in the shrub cover and herbaceous and grass species richness. Bush cover homogenisation suggests that the effects of fire were short-term in controlling bush encroachment. The periodic fires that were caused by deliberate burning by the Owambo herders provided short-term opportunity for the bush cover to be reduced and the herbaceous layer promoted. Some landscapes (e.g. *Ehenga-Omufitu*) were burned more frequently to induce the growth of the herbaceous layer and woody plant post-fire sprouts. The findings showed that the trends of the cover and richness of life forms at landscape and regional scales were non-linear, showing that frequent fires reduced shrub cover in the short-term. However, the frequent fires positively influenced the herbaceous and tree species. Repeated burning created patch mosaics of vegetation reflecting different stages of recovery at the landscape scales. There was however no evidence that the anthropogenic fires reduced the biodiversity of the savanna vegetation. The findings show that the methods of integrating herder knowledge for reconstructing fire history in parallel with ecological assessments of the fire impacts have an important role to play in the future monitoring and development of fire management policy guidelines for savanna ecosystems in Namibia.

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