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BUSH ENCROACHMENT CONTROL DEMONSTRATIONS AND MANAGEMENT IMPLICATIONS ON HERBACEOUS SPECIES IN SAVANNAS OF SOUTHERN ETHIOPIA

[CONTROL DE MALEZAS ARBUSTIVAS E IMPLICACIONES DE ESTE MANEJO SOBRE ESPECIES HERBACEAS DE LA SAVANA DEL SURESTE DE ETIOPIA]

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SUMMARY

Proper management of bush control methods need to be effectively demonstrated to resource users. In this paper, we evaluated effects of disturbance control (CO) (i.e., government policy approach in the conservation of natural resources), tree cutting and fire (C+F), tree cutting, fire and grazing (C+F+G), the old traditional method of applying fire and grazing (F+G) by herders, grazing with bush cover (GBC) (i.e., current system of land use system by herders in Borana) and tree cutting alone (C) (i.e., Non-governmental Organizations approach in rangeland improvement) on herbaceous species composition, abundance, biomass, basal cover and species diversity in southern Ethiopia. The disturbance control demonstration showed no advantage in terms of biomass and basal cover over other treatments, although herbaceous species richness was improved. Bush removal methods such as tree cutting and fire, tree cutting followed by fire and grazing, fire and grazing, and tree cutting alone improved herbaceous biomass, basal cover and species diversity, while grazing alone greatly reduced herbaceous biomass. Tree cutting and fire treatments seemed superior in terms of herbaceous biomass, while conservation of herbaceous species diversity was improved more by the traditional method of fire and grazing, and tree cutting. With the exception of species richness, protection from disturbance showed no advantage. Only fire and grazing methods can reasonably be applied for the control of bush encroachment with the overall objective of promoting biomass production and species diversity.

Key words: Disturbance control; tree cutting, fire, grazing; policy implication; public education; Ethiopia.

RESUMEN

Es necesario demostrar la efectividad de los métodos de manejo y control de malezas arbustivas para manejar los recursos naturales. Este artículo evalúa los efectos del control de perturbación (CO) (ejem. Política gubernamenta en la conservación de recursos naturales), tala de árboles y quema (C+F), tala, fuego y pastoreo (C+F+G), el método tradicional de fuego y pastoreo (F+G) empleado por pastores, pastoreo con la cubierta vegetal arbustiva (GBC) (ejem. El sistema actual de uso de la tierra por pastores en Borana) y la tala de árboles únicamente (C) (ejem. El enfoque recomendado por organizaciones no gubernamentales para el mejoramiento del agostadero) sobre la composición de especies arbustivas, abundancia, biomasa, cobertura y diversidad de especies en el sureste de Etiopía. El método CO no mostró ventajas en términos de biomasa y cobertura sobre los otros tratamientos, aunque la riqueza de especies herbáceas fue mejorada. Los métodos de remoción de maleza tales como la tala seguida de quema y pastoreo, quema y pastoreo y, sólo tala, mejoraron la biomasa herbácea, la cobertura y la diversidad de especies, mientras que el sólo pastoreo redujo grandemente la biomasa de herbáceas. La tala y la quema parecen ser mejores en términos de biomasa herbáceas, mientras que la conservación de la diversidad de especies es mejor con el método tradicional de quema y pastoreo y, y tala. Con excepción de la riqueza de especies, la protección de la perturbación no presentó ventajas. Únicamente la quema y el pastoreo pueden ser razonablemente implementados para el control de malezas arbustivas con el objetivo de promover la producción de biomasa y diversidad de especies.

Palabras clave: Control de pertubación; tala; quema; pastoreo; políticas y educación pública; Ethiopia.

INTRODUCTION

Savanna grasslands are threatened by bush encroachment worldwide (Scholes and Archer, 1997; Oba et al., 2000; Smit and Rethman, 2000; Sheuyange et al., 2005; Wiegand et al., 2005) through the suppression of herbaceous biomass production and probably reduced biodiversity (Smit, 2003; Hagos and Smit, 2005; Ansley and Castellano, 2006). The threat to the pastoral economy is often the main reason for the control of bush encroachment (Olson and Whitson, 2002). Bush encroachment control is a disturbance that reduces the threat of bush encroachment by disrupting the invasive woody plant community structure through transformations of biotic environments and habitat conditions in which colonization of the disturbed microhabitat takes place (Pickett and White, 1985). Bush encroachment control methods shift the savanna vegetation from dominance by woody vegetation to dominance by herbaceous vegetation thereby creating suitable habitat for grazers (Fulbright, 1996; Hudak, 1999; Angassa and Oba, 2008). The shift towards herbaceous species dominance in turn induces shifts in species that are intolerant of bush cover, while the species that tolerate bush cover might decline (Clarke et al., 2005). The changes could cause partial or total reduction of plant biomass (Grime, 1977) by shifting vegetation structure and composition (Łaska, 2001). Disturbance can also produce changes in the life history strategies of individual species in response to intensities of disturbance forces (Grime, 1974; Grime, 1977) and the created micro-environmental conditions (Vetaas, 1992).

In savanna ecosystems, different bush control methods including hand removal of trees (Berlow et al., 2003; Smit, 2003, 2004), use of fire (Sheuyange et al., 2005), combination of hand removal and burning (Duggin and Gentle, 1998; Olson and Whitson, 2002), tree cutting combined with fire and grazing (Kobayashi et al., 1997; Sawadogo et al., 2002; Sawadogo et al., 2005), fire combined with grazing (Fuhlendorf and Engle, 2004; Sawadogo et al., 2005) and grazing control (Fulbright, 1996; Smit, 2004; Bates, 2005) are commonly used to increase herbaceous production and species diversity (Smit, 2003; Ansley and Castellano, 2006). Tree cutting and prescribed fire followed by rest from grazing enhanced herbaceous plant biodiversity (Bates, 2005). Others (Kobayashi et al., 1997; Sawadogo et al., 2005) also studied effects of tree cutting, fire and grazing on the responses of herbaceous plants. Previous studies (Hutchinson et al., 2005) have observed changes in herbaceous species richness following prescribed fire, while Fuhlendorf and Engle (2004) reported the importance of fire and grazing in the restoration of savanna grasslands. Cutting is effective in increasing herbaceous biomass, cover and diversity (Bates et al., 2000). Changes in relative abundance of herbaceous species over time may be a good indicator of species' responses to disturbances compared to pre-disturbance populations. Elsewhere, the importance of bush encroachment control in improving the relative abundance of herbaceous species has been shown (Hudak, 1999). Relative abundance serves as an indicator of population of individual plants that could vary in response to disturbances. The effects of different bush control methods on herbaceous production and diversity can therefore be evaluated in terms of herbaceous species performances (Fulbright, 1996).

Bush encroachment control methods are management systems (Fulbright, 1996) that might have varied policy implications for bush control (Olson and Whitson, 2002). Understanding the potential role of different bush encroachment control methods for promoting herbaceous species composition requires recognition of the objectives of resource users and policymakers. The resource users are interested in livestock production through increased plant productivity, while the goal of policymakers is environmental preservation. The public is likely to adopt management systems that are more efficient in improving forage for livestock grazing, while official government policy promotes the conservation of biodiversity. The two goals may be in conflict. Although the effects of bush encroachment control methods on herbaceous plants have been well documented (Hadar et al., 1999; Angassa, 2002; Sawadogo et al., 2002; Smit, 2003, 2004; Sawadogo et al., 2005; Ansley and Castellano, 2006), information regarding the potential role of such demonstrations in influencing management policies and public education is limited.

In the Borana pastoral region of southern Ethiopia, which is the focus of the present study, we are not aware of other efforts in which bush encroachment control were purposely used to evaluate responses of individual herbaceous species to recommend management policy. Researchers and the extension departments concerned with grazing lands rarely design bush encroachment controls to promote the management of bush cover or discuss the educational benefits of different methods in terms of long-term changes in the relative abundance of herbaceous species and biomass for livestock forage. Monitoring the effects of various control methods is useful in highlighting single and combined effects of disturbances on herbaceous vegetation, by providing evidence of changes in species composition over time and assessing management policy and public educational relevance.

We evaluated the effects of six demonstration methods including disturbance control (CO) (i.e., exclude grazing and other disturbances), tree cutting and fire (C+F), tree cutting, fire and grazing (C+F+G), fire and grazing (F+G) (which is the old traditional method practiced by pastoralists before the official ban on the use of fire), grazing with bush cover (GBC) (which is representing the current methods of pastoral land use), and tree cutting alone (C) on: (a) changes in species composition and the relative abundance of individuals of each herbaceous species; (b) trends in the relative abundance of herbaceous species; (c) performances of individual herbaceous species; and (d) changes in biomass, basal cover and species diversity between the pre- and post- treatment sampling periods. The findings are then discussed in the light of policy guidelines for bush encroachment control, as well as recommendations for sound public education on the post-treatment management of the savanna ecosystems in southern Ethiopia.

MATERIALS AND METHODS

Study area

We demonstrated six bush encroachment control treatments replicated across the government cattle breeding ranch (in Dida-Tuyura 04º57.383´N, 38º12.403E´) and community ranch (in Dambala-Wachu, 04º29.432´N, 38º16.339´E) in southern Ethiopia. The topography varies from uplands (> 1500 m a.s.l.) to bottomlands (< 1400 m a.s.l.). The major soil types are Chromic and Orthic Luvisols (45%), Calcaric and Eutric Regosols (15.25%), and Lithosols together with Humic, Mollic and Vertic Andosols (FAO, 1986; Coppock, 1994). The climate is variable with the main rainy season from March - May (*ganna*) and the short rains from September - November (*hagaya*). The mean annual rainfall for the period 1980 to 2000 was 513±39 mm for Dida-Tuyura and 359±30 mm for Dambala-Wachu. In both sites, bush encroachment pose problems for livestock grazing. Before the two range sites were converted into ranches and prior to the official ban on fire in the 1970s, the pastoral community periodically conducted range burning late in the dry season (the dry season occurs between December and early March). Under the ranch management system, the sites, similar to the communal rangelands lacked regular burning. At the time of the research, the stocking density of the Dida-Tuyura ranch was 12.0 Tropical Livestock Unit km^{-2} (TLU km^{-2}, 1 TLU = 250 kg bovine) compared to 17.6 TLU km^{-2} in Dambala-Wachu (Angassa and Oba, 2007).

The dominant vegetation-type of the ranches is *Acacia* grassland and consists mostly of perennial grasses and woody cover. The grass cover is dominated by *Cenchrus ciliaris, Chrysopogon aucheri* and *Panicum coloratum*, while the woody cover consists mainly of *Acacia drepanolobium* on black soil sites, and *A. brevispica* and *A. horrida* in the uplands (Coppock, 1994). There are also patches of *Balanites aegyptica*, and several species of *Commiphora* and *Terminalia* at the lower altitudes. The higher parts of the hills used to be covered with *Juniperus procera* and *Olea europaea cuspidata* forest (Coppock, 1994).

We selected the ranch sites considering their use as demonstration plots to the local communities for extension services. We used the opportunity to demonstrate different bush encroachment control methods where this can also serve the extension department for further education and communication to resource users to encourage local participation in future management of bush-control.

Sampling methods

Six demonstrations practices were conducted, including disturbance control (CO) that represented the government policy to exclude fire, grazing and tree cutting, in which grazing was excluded by fencing. The second demonstration practice combined tree cutting and fire (C+F) and the third practice was tree cutting followed by fire and grazing (C+F+G). The fourth demonstration represented the old traditional system that combines fire and grazing management (F+G), for which fencing was not necessary. The fifth demonstration, grazing with bush cover (GBC), represented the current traditional system (i.e., after government banned the use of fire) of rangeland management. On both ranches, grazing was conducted using free ranging animals. For plots in the sixth demonstration (cutting alone denoted by C), all trees were hand cleared followed by fencing to protect the area from livestock grazing. All tree clearings were unselective, involving removal of all trees. This is the method of bush encroachment control commonly used by Non-Governmental Organizations (NGOs) for rangeland rehabilitation.

In the demonstration where we combined tree cutting followed by fire and grazing (C+F+G), the woody plants were chopped up into finer pieces and then piled on tree stumps to create a fine fuel load for burning. The piles of woody plants were allowed to dry for one month before fire was ignited. The C+F demonstration plots were fenced in June 2003 to exclude livestock to allow the accumulation of fuel loads before burning. The fourth demonstration represented the traditional use of fire (before official fire suppression) and grazing (F+G), in which livestock was allowed to graze the burnt plots. The three burn demonstrations (i.e., C+F, C+F+G and F+G) were conducted late in the dry season. Details of the burning treatments are presented in Part I of this experiment (Angassa and Oba, 2009).

For all demonstrations, we randomly distributed twenty-four 50 x 50 m plots in both topographic locations. In each of the larger plots, we randomly located three smaller 1 x 1 m plots for sampling herbaceous vegetation during pre-treatment in 2003. Sampling was repeated on the same plots during the post-demonstration phases in 2004 and 2005. During each sampling process, all the herbaceous species were identified (where species could not be identified the voucher samples were collected for later identification), and numbers of individuals of each species (i.e., relative abundance) per m^2 and the species richness were determined per plot per census (i.e., total count of all species per plot). Unidentified herbs and forbs, hereafter referred to as "other herbaceous species" and "herbaceous legumes", were also included in species richness. The species diversity index, H´ = -(∑ (pilnpi)) (Shannon, 1948) was calculated using the frequency of each plant species (where pi represents the proportion of individual species in each plot). The basal cover of root crown in relation to the bare ground was estimated for each species or categories of species (i.e., including unidentified herbaceous and leguminous species). All the herbaceous plants in the sample plots were hand harvested. The combined samples of the species were air dried followed by oven drying at 65°C for 48 hours, for the purpose of dry matter estimation. In this study, we focused on the performances of individual herbaceous species between the pre- and post-demonstration treatments. During the sampling periods, the treatments were aimed at demonstrating to the local communities on how different bush encroachment control methods influenced the performances of different species. More importantly, we used the results to inform the general public using our simplified experimental design.

Analyses

We report mean values (i.e., by combining data from the two ranches and the two landscape locations), by sampling dates, by demonstration treatments. We used a general linear model in SAS to analyze the pre- and post-disturbance mean (±SE) of the relative abundance of individual species. We used descriptive statistics to calculate relative changes (i.e., differences in relative abundance – represented by numbers of individuals of each species between the pre- and post-disturbance) of individual species m^{-2}. A chi-square test was used to analyze changes in the relative abundance of individual species, to determine their susceptibility (i.e., species performance) to the effects of the demonstration (Sweet and Tacheba, 1984). Least significant difference (LSD) was used to analyze changes in biomass, basal cover and diversity between the pre- and the post-disturbance for each demonstration.

RESULTS

Disturbance control

Prior to protection, the disturbance control (CO) demonstration had 9 herbaceous species, which after two years of protection increased to 18 (Tables 1 and 2). Species recorded after establishing protection included: *Aristida adoensis, Bothriochloa radicans, Digitaria milanjiana, Enteropogon somalensis, Harpachne schimperi*, *Heteropogon contortus* and *Panicum turgidum* (Tables 2 and 3). *Cenchrus ciliaris, Chloris roxburghiana, Leptothrium senegalense, Panicum coloratum* and *Sporobolus pyramidalis* slightly increased in relative abundance in response to protection, while *Eragrostis papposa* and *Panicum maximum* were reduced (Tables 1, 2, 3 and 4). We found no changes in the relative abundance of *Chrysopogon aucheri* and *Themeda triandra* in response to protection (Tables 1, 2 and 3). Before protection, the most abundant species was *Eragrostis papposa* followed by *Panicum maximum*, but both of them declined in response to protection. *Bothriochloa radicans* was the most abundant species after two years of protection (Tables 1 and 2). Protection did not increase herbaceous biomass, basal cover and diversity (Figs. 1 a, b, c).

Tree cutting and fire

The tree cutting and fire (C+F) demonstration increased herbaceous species richness from 9 (i.e., pre-disturbance) to 15 (i.e., after disturbance) (Tables 1 and 2). Of the initial herbaceous species, *Cenchrus ciliaris* increased in relative abundance, while about 78% of the pre-treatment species showed a decline (Tables 1, 2 and 3). Only in the case of *Sporobolus pyramidalis* was the decline significant (Tables 3 and 4). Generally, the most abundant species was *Sporobolus pyramidalis* followed by *Eragrostis papposa* preceding disturbance, while *Chrysopogon aucheri* did not vary in relative abundance during post-disturbance (Tables 1 and 2). Herbaceous biomass and species diversity, but not basal cover, were greatly promoted during the post-disturbance period (i.e., in 2005) compared to the pre-disturbance period (Figs 1 a, b, c).

Tree cutting - fire and grazing

In response to tree cutting, fire and grazing (C+F+G), herbaceous species richness increased from 9 (pre-disturbance) to 17 (after disturbance) (Tables 1 and 2). The species *Bothriochloa radicans, Cynodon dactylon, Enteropogon somalensis, Eragrostis sennii, Heteropogon contortus, Panicum turgidum* and *Sporobolus pyramidalis* were not captured during the pre-demonstration sampling, but were recorded after disturbance (Tables 2 and 3). Among the initial herbaceous species, only *Leptothrium senegalense* was greatly promoted by the combined effects of tree cutting, fire and grazing (Table 3). Hence, tree cutting, fire and grazing reduced relative abundance of most herbaceous species at first, followed later by increases (Tables 1, 2 and 3). The decline of *Chloris roxburghiana, Eragrostis papposa* and *Panicum coloratum* was significant (Tables 3 and 4). The species absent from the post-demonstration period was *Aristida adoensis,* while the species that declined (e.g., *Eragrostis papposa* and *Lintonia nutans)*. *Eragrostis papposa* appeared to be the most abundant species prior to disturbance, exception being *Sporobolus pyramidalis* with increased relative abundance following disturbance (Tables 1 and 2). During the post-demonstration periods herbaceous biomass and diversity, but not basal cover, showed increases (Figs 1 a, b, c).

Fire and grazing

The fire and grazing (F+G) demonstration promoted herbaceous species richness from 11 (pre-disturbance) to 21 (after disturbance) (Tables 1, 2 and 3). *Enteropogon somalensis, Panicum maximum* and *Pennisetum stramineum* increased in abundance during post-disturbance (Tables 3 and 4). However, about 82% of the individuals declined in relative abundance during the post-disturbance periods (Tables 1, 2 and 3). Among the species that showed significant declining in trends were *Cenchrus ciliaris, Sporobolus pyramidalis* and *Themeda triandra* (Tables 3 and 4). The species most vulnerable to fire and grazing and also absent from the post-demonstration periods were *Aristida adoensis* and *Leptothrium senegalense* (Tables 2 and 3). The two most disturbance tolerant species were *Heteropogon contortus* and *Sporobolus pyramidalis*. Herbaceous biomass and diversity, but not basal cover, increased in response to fire and grazing (Figs 1 a, b, c).

Grazing with bush cover

Grazing with bush cover (GBC) promoted herbaceous species richness from 11 to 20 species (Tables 1, 2 and 3). Among the initial herbaceous populations, the species that positively responded to grazing with bush cover were *Cenchrus ciliaris, Hyparrhenia hirta* and *Panicum coloratum* (Tables 3 and 4). Among the key species that showed significant declines in relative abundance were *Chrysopogon aucheri, Eragrostis papposa, Pennisetum stramineum, Sporobolus pyramidalis and Themeda triandra* (Tables 3 and 4), while *Lintonia nutans* showed stability in response to grazing (Tables 1, 2 and 3). *Chrysopogon aucheri* was the most abundant species during pre-disturbance, while *Sporobolus pyramidalis* was more abundant after disturbance (Tables 1 and 2). Grazing with bush cover reduced herbaceous biomass and basal cover, while species diversity was promoted (Figs 1a, b, c).

Table 1. Pre-disturbance mean (± SE) of herbaceous species in terms of abundance of individuals recorded in 2003 in different demonstration plots (mean of 12 plots of 1m^2) in Borana, southern Ethiopia.

Species list	Demonstration plots Control[a]	C+F[b]	C+F+G[c]	F+G[d]	GBC[e]	C[f]
Aristida adoensis Hochst.			4±2.6	2±1.1		8±3.4
Cenchrus ciliaris L.	10±4.2	14±11.8	12±8.1	43±8.1	3±1.2	6±2.5
Chrysopogon aucheri (Boiss.) Stapf.	9±4.2	25±9.1	18±4.8	14±2.0	45±5.9	21±7.7
Chloris roxburghiana Schult.	3±1.4	3±1.8	2±1.6	1±0.1		6±1.4
Eragrostis papposa (Roem. & Schult.) Stued.	48±17.4	52±11.2	63±14.8	17±8.1	13±10.2	19±7.7
Heteropogon contortus (L.) Beauv. ex. R. & Sch.				78±38.1		
Hyparrhenia hirta (L.) Stapf.					6±5.2	
Leptothrium senegalense (Kunth) Clayton	4±2.7	12±5.8	1±0.6	2±1.2		2±1.4
Lintonia nutans Stapf.		12±5.8	37±5.6		2±1.2	18±13.4
Panicum maximum Jacq.	31±14.7			1±0.1		
Panicum coloratum L.	8±7.4	8±5.8	16±5.6	9±2.0	2±1.2	
Pennisetum mezianum (Vahl) Lanza & Mattei					4±1.2	
Pennisetum stramineum Peter					14±11.2	
Sporobolus pyramidalis Beauv.	14±4.7	63±15.2		78±27.0	41±7.2	24±13.4
Themeda triandra Forssk.	9±4.7	32±15.8	31±18.1	10±7.0	6±5.2	14±9.5
Other herbaceous species (unidentified)					13±10.2	5±3.4

aControl = exclusion of cutting, grazing and fire, bC+F = combination of cutting and fire, cC+F+G = combination of cutting, fire and grazing, dF+G = combination of fire and grazing, eGBC = Grazing under increased bush cover, fC = Cutting alone

Table 2. Post-disturbance mean (± SE) of herbaceous species in terms of abundance of individuals recorded in 2004 and 2005 in response to the different demonstration methods (mean of 12 plots of 1m^2) in Borana, southern Ethiopia.

Species list	Demonstration plots					
	Control	C+F	C+F+G	F+G	GBC	C
Aristida adoensis Hochst.	3±2.6	3±1.2			1±0.6	3±1.2
Bothriochloa radicans (Lehm.) A.Camus	43±7.9		8±5.5		17±7.7	22±9.4
Cenchrus ciliaris L.	17±4.0	18±6.5	11±5.2	15±6.0	13±4.9	15±4.7
Chrysopogon aucheri (Boiss.) Stapf.	9±3.2	26±6.5	15±4.4	9±4.8	12±4.1	11±3.3
Chloris roxburghiana Schult.	5±2.6	1±0.6	1±0.5	2±1.5		8±2.4
Cynodon dactylon (L.) Pers.			12±10.5	1±0.5	5±1.8	4±3.4
Cyperus species Vahl.				2±1.5		4±1.4
Digitaria milanjiana (Rendle) Stapf.	1±0.9					
Eleusine jaegeri Pilg.						4±4.4
Enteropogon somalensis Chiov.	12±7.9	5±3.2	6±1.5	9±8.5	12±7.7	6±4.4
Eragrostis papposa (Roem. & Schult.) Stued.	2±1.7	8±3.2	1±0.5	5±1.5	3±1.8	7±4.4
Eragrostis sennii Chiov.			1±0.5	1±0.5		
Harpachne schimperi Hochst. ex. A. Rich.	1±0.9			1±0.5	3±1.8	3±2.6
Heteropogon contortus (L.) Beauv. ex. R. & Sch.	5±4.7		15±10.5	36±9.5	7±5.8	8±4.4
Hyparrhenia hirta (L.) Stapf.					16±10.8	
Leptothrium senegalense (Kunth) Clayton	5±3.6	1±0.9	11±10.5		1±0.8	
Lintonia nutans Stapf.		1±0.7	1±0.5		2±1.7	
Panicum maximum Jacq.	12±7.9			13±13.5	1±0.8	10±9.4
Panicum coloratum L.	11±5.6	5±3.4	14±7.4	7±3.5	13±6.3	5±2.4
Panicum turgidum Forssk.	9±7.9	17±14.5	4±1.5	2±1.5		2±1.5
Pennisetum mezianum (Vahl) Lanza & Mattei				2±1.5	3±1.8	1±0.5
Pennisetum stramineum Peter		18±14.5		9±3.5	11±10.8	
Sporobolus pyramidalis Beauv.	23±4.6	25±6.5	19±7.4	17±5.5	19±6.2	18±3.6
Themeda triandra Forssk.	9±5.6	6±4.2	18±6.1	9±7.9	4±3.7	9±5.4
Herbaceous legumes (unidentified)	7±4.0	6±3.7	13±6.1	17±7.9	8±4.9	4±3.2
Other herbaceous species (unidentified)	6±3.9	18±14.5	12±10.5	18±7.9	6±4.8	9±6.6

Tree cutting

Compared to the initial populations, herbaceous species richness doubled during the post-demonstration period in response to tree clearing (Tables 1, 2 and 3). Among the newly recorded species, the changes were significant for *Bothriochloa radicans, Heteropogon contortus* and *Panicum maximum* (Tables 3 and 4). Among the initial herbaceous species recorded (n = 10 herbaceous species), about 70% exhibited declining trends (Tables 1, 2 and 3). Overall, *Aristida adoensis, Chrysopogon aucheri, Eragrostis papposa, Lintonia nutans and Themeda triandra* were greatly reduced in response to tree cutting (Tables 3 and 4). The species most sensitive to the tree cutting treatments were Leptothrium senegalense and Lintonia nutans (Tables 2 and 3), while the most stable species were *Sporobolus pyramidalis* and *Bothriochloa radicans*. Herbaceous biomass and diversity increased by nearly 50% compared to the pre-cutting period, while basal cover showed no improvement (Figs 1 a, b, c).

DISCUSSION

Disturbance control

The official policy of banning the use of fire was aimed at conserving forest cover, but was less concerned with forage production. For the local herders, bush encroachment threatens forage production, which is the feed for the grazing livestock. We were therefore interested to know if the post-disturbance effects of bush encroachment control could be reflected by the performances of individual herbaceous species. We showed that species richness under the disturbance control method was comparable to the disturbance treatments (see below). The dynamics of herbaceous species under bush encroachment are likely to have been influenced by environmental conditions associated with bush cover. Bush cover creates microhabitats that favour some species that were less common in the open (disturbed) habitats. Species that were tolerant to bush cover were promoted, while those that were intolerant were reduced in the absence of disturbance (Osem et al., 2002; Clarke et al., 2005). The dynamics of herbaceous species under bush cover probably reflect the role played by the soil seed bank (Solomon et al., 2006), which might account for the new species. We also considered potential competition between herbaceous species and bushy plants. We confirmed herder concerns about the negative role of bush cover on herbaceous biomass production. Our data also showed that herbaceous plant basal cover and herbaceous species diversity are not promoted under bush cover (Jacobs and Schloeder, 2003). The evidence might suggest that protection from human induced disturbances, as promoted by state conservation policies, has failed to promote production of herbaceous biomass, which is contrary to herder objectives.

Table 3. Trends of individual species and average relative change in terms of abundance in response to the different demonstration methods (mean of 12 plots of $1m^2$) in Borana, southern Ethiopia. Average relative change = average no. of individuals recorded during post-demonstration – average no. of individuals observed during pre-demonstration.

	Demonstration plots					
Species list	Control[a]	C+F[b]	C+F+G[c]	F+G[d]	GBC[e]	C[f]
Aristida adoensis Hochst.	3*	3*	−	−	1*	↓5
Bothriochloa radicans (Lehm.) A.Camus	43*		8*		17*	22*
Cenchrus ciliaris L.	↑7	↑4	↓1	↓28	↑10	↑9
Chrysopogon aucheri (Boiss.) Stapf.	nc	↑1	↓3	↓5	↓33	↓10
Chloris roxburghiana Schult.	↑2	↓2	↓1	↑1		↑2
Cynodon dactylon (L.) Pers.			12*	1*	5*	4*
Cyperus species Vahl.				2*		4*
Digitaria milanjiana (Rendle) Stapf.	1*					
Eleusine jaegeri Pilg.						4*
Enteropogon somalensis Chiov.	12*	5*	6*	9*	12*	6*
Eragrostis papposa (Roem. & Schult.) Stued.	↓46	↓44	↓62	↓12	↓10	↓12
Eragrostis sennii Chiov.			1*	1*		
Harpachne schimperi Hochst. ex. A. Rich.	1*			1*	3*	3*
Heteropogon contortus (L.) Beauv. ex. R. & Sch.	5*		15*	↓42	7*	8*
Hyparrhenia hirta (L.) Stapf.					↑10	
Leptothrium senegalense (Kunth) Clayton	↑1	↓11	↑10	−	1*	−
Lintonia nutans Stapf.		↓11	↓36		nc	−
Panicum maximum Jacq.	↓19			↑12	1*	10*
Panicum coloratum L.	↑3	↓3	↓2	↓2	↑11	5*
Panicum turgidum Forssk.	9*	17*	4*	2*		2*
Pennisetum mezianum (Vahl) Lanza & Mattei				2*	↓1	1*
Pennisetum stramineum Peter		18*		9*	↓3	
Sporobolus pyramidalis Beauv.	↑9	↓38	19*	↓61	↓22	↓6
Themeda triandra Forssk.	nc	↓26	↓13	↓1	↓2	↓5
Herbaceous legumes (unidentified)	7*	6*	13*	17*	8*	4 *
Other herbaceous species (unidentified)	6*	18*	12*	18*	↓7	↑4

↑ = Increase, ↓ = Decline, − = lost, nc = No change, * = indicates species regeneration

aControl = exclusion of cutting, grazing and fire, bC+F = combination of cutting and fire, cC+F+G = combination of cutting, fire and grazing, dF+G = combination of fire and grazing, eGBC = Grazing under increased bush cover, fC = Cutting alone

Tree cutting and fire

The control of bush encroachment by means of tree cutting and fire increased the richness and relative abundance of herbaceous species during post-disturbance periods. The new herbaceous species that were recorded in response to the tree cutting and fire demonstrations are probably those that decreased under bush encroachment. These species responded more positively to disturbance, which might suggest that they would be poor competitors under conditions of bush encroachment (Duggin and Gentle, 1998; Berlow et al., 2003). Under these disturbance conditions, the bush cover tolerant species became poor competitors. The initial decline in the relative abundance of most herbaceous species to tree cutting and fire was probably related to shifts in the micro-environment following the removal of ecologically important trees. The bush cover tolerant species were reduced, while the intolerant species were promoted. Furthermore, the species that declined were probably more sensitive to fire than the other (fire tolerant) species. We confirmed that combinations of tree cutting and fire promoted herbaceous biomass more than grazing and fire or cutting alone (see Fig. 1a). Woody plant encroachment control followed by resting would improve the restoration of herbaceous biomass and plant biodiversity over time. In terms of management, the C+F demonstration methods created a dilemma between conserving disturbance-sensitive herbaceous species and promoting the disturbance-tolerant species. For the herders, the demonstration showed more beneficial gains in terms of biomass in the long-term, although in the short-term the benefits were less. This demonstration suggests that the management strategy needs to be planned so that rest follows treatments, at least for a year or two, before grazing by livestock is resumed. This kind of management strategy has been promoted by the community during the pre-fire ban decades (i.e., before the 1970s) and is more appropriate for range enclosures near settlements than the larger communal grazing lands (Angassa and Oba, 2008).

Table 4. Chi-square (χ^2-tests) for herbaceous species in terms of performance of individuals in response to the effects of different demonstration plots in Borana, southern Ethiopia.

	Demonstration plots					
Species list	Control[a]	C+F[b]	C+F+G[c]	F+G[d]	GBC[e]	C[f]
Aristida adoensis Hochst.	0.81^{NS}	1.07^{NS}	0.71^{NS}	0.77^{NS}	^{NS}	5.40*
Bothriochloa radicans (Lehm.) A.Camus	8.48**		0.13^{NS}		21.73***	6.60*
Cenchrus ciliaris L.	7.07*	0.03^{NS}	0.02^{NS}	15.53***	13.71***	2.06^{NS}
Chrysopogon aucheri (Boiss.) Stapf.	0.02^{NS}	0.49^{NS}	0.21^{NS}	2.74^{NS}	13.38***	8.53**
Chloris roxburghiana Schult.	2.60^{NS}	0.69^{NS}	6.74*	^{NS}		10.36**
Cynodon dactylon (L.) Pers.			0.32^{NS}	^{NS}	^{NS}	0.52^{NS}
Cyperus species Vahl.				^{NS}		0.52^{NS}
Digitaria milanjiana (Rendle) Stapf.	0.06^{NS}					
Eleusine jaegeri Pilg.						2.67^{NS}
Enteropogon somalensis Chiov.	1.62^{NS}	0.87^{NS}	0.20^{NS}	5.99*	0.85^{NS}	1.98^{NS}
Eragrostis papposa (Roem. & Schult.) Stued.	22.07***	1.20^{NS}	8.66 **	4.66*	1.76^{NS}	5.79*
Eragrostis sennii Chiov.				0.84^{NS}		
Harpachne schimperi Hochst. ex. A. Rich.	0.48^{NS}			0.09^{NS}	7.25*	2.88^{NS}
Heteropogon contortus (L.) Beauv. ex. R. & Sch.	^{NS}		0.02^{NS}	1.75^{NS}	12.04**	12.60***
Hyparrhenia hirta (L.) Stapf.					13.48***	
Leptothrium senegalense (Kunth) Clayton	2.34^{NS}	2.37^{NS}	2.93^{NS}	^{NS}	2.80^{NS}	3.63^{NS}
Lintonia nutans Stapf.		2.06^{NS}	^{NS}		2.24^{NS}	12.95***
Panicum maximum Jacq.	18.18***			27.22***	2.48^{NS}	13.98 ***
Panicum coloratum L.	3.48^{NS}	1.21^{NS}	3.86*	11.25**	4.93*	0.28^{NS}
Panicum turgidum Forssk.	3.67^{NS}	0.76^{NS}	1.83^{NS}	^{NS}		
Pennisetum mezianum (Vahl) Lanza & Mattei					2.84^{NS}	
Pennisetum stramineum Peter		0.78^{NS}		14.33**	6.11*	
Sporobolus pyramidalis Beauv.	4.84*	5.64*	1.37^{NS}	12.78 ***	11.65**	1.22^{NS}
Themeda triandra Forssk.	^{NS}	0.17^{NS}	1.10^{NS}	23.84***	43.18***	6.67*
Herbaceous legumes (unidentified)	0.63^{NS}	0.08^{NS}	0.37^{NS}	3.74^{NS}	6.99*	6.68*
Other herbaceous species (unidentified)	0.43^{NS}	1.74^{NS}	0.01^{NS}	^{NS}	5.61*	4.55*

* = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$, NS = not significant

aControl = exclusion of cutting, grazing and fire, bC+F = combination of cutting and fire, cC+F+G = combination of cutting, fire and grazing,

dF+G = combination of fire and grazing, eGBC = Grazing under increased bush cover, fC = Cutting alone

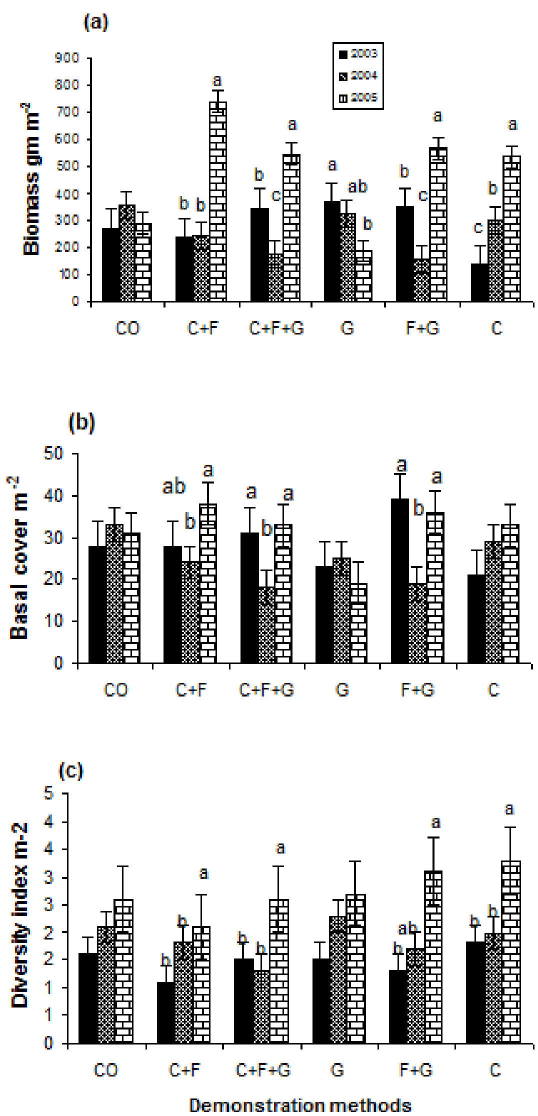

Figure 1. Responses of: (a) herbaceous biomass; (b) basal cover; and (c) species diversity to six bush encroachment control demonstration methods in Borana, southern Ethiopia.

Tree cutting, fire and grazing

The combination of tree cutting, fire and grazing (C+F+G) differed from C+F by introducing grazing into the demonstration, and evaluating plant performances thereafter. This demonstration method represented active management, and by not excluding livestock grazing, was more likely to be acceptable to the herders. Our data showed that herbaceous species richness was highly promoted. The combined treatments might have improved growth conditions of a few species, which increased (11%), while the greater majority of the species that declined in abundance (89%) were probably less tolerant to the treatment combinations. The post-demonstration responses by individual species reflected both the seasonal variability of rainfall (data not shown) and improved environmental conditions for seed germination. For the most sensitive species, tree cutting, fire and grazing disturbances were initially followed by decline in relative abundance (Kobayashi et al., 1997). This decline could be explained either as a result of competition for resources among species (Clarke et al., 2005), seasonal fluctuations in relation to the life history of individual species (Elliott et al., 1997; Deil, 2005; Gőtmark et al., 2005) or variations in the soil seed bank (Solomon et al, 2006). Other species declined due to lack of tolerance to disturbance (Osem et al., 2002). Our results suggest that tree cutting, fire and grazing treatments were soon followed by decline in herbaceous biomass, basal cover and diversity, but in the long-term the effects were positive on herbaceous biomass and diversity.

The decline in herbaceous biomass soon after disturbance may be attributed to the effect of tree removal that reduced bush cover tolerant species, which were dominant prior to the demonstration. It is possible that the treatments reduced the abundance of the bush cover tolerant species and therefore the biomass. After the treatments, the species that tolerated disturbance took a while to build and produce more biomass. For purposes of management, therefore, it appears that grazing might need to be delayed after the hand removal and burning of the woody vegetation. The introduction of grazing after resting might allow a rapid build-up of the biomass. Currently, in southern Ethiopia, this type of management has been initiated through the activities of Non-Governmental Organizations (NGOs) that utilize community labour to clear land in limited areas. However, regulations for grazing systems (e.g. rest followed by grazing) have not been put in place, other than those used by the Borana herders, which involves resting of the treated areas during the wet season and grazing the fallow during the dry season by young and old livestock.

Community adaptation of the system would be constrained by a shortage of labor for land clearing. Thus, the use of these demonstration methods would be more viable in areas near settlements, where the community often grazes calves and old animals or saves fodder reserves for the dry and drought periods. The usual practice is for women to travel long distances to collect hay for calves kept at home. The C+F+G demonstration method could easily be incorporated into the traditional system of pasture management, if it is aimed at community management of fodder for the most vulnerable animal classes (e.g. calves and old animals). However, this method is unlikely to be suited to the wider rangelands that are currently suffering from bush encroachment, due to the cost of land rehabilitation. We therefore emphasize the importance of these demonstration methods for pasture management at settlement levels, which could easily be integrated into the existing systems of land use.

Fire and grazing

The fire and grazing combination represents the old traditional system of rangeland management used by the Borana pastoralists. Traditionally, the society burnt areas of the range periodically where bush cover posed a threat or the grass layer was over-mature and losing its nutritive value. The fire killed young woody plants and opened up the under-story vegetation for better growth of herbaceous vegetation. The system of burning was not random, but planned. It is therefore important to understand the responses of herbaceous species to fire and grazing under conditions comparable to the traditional system of fire use. The method of fire management by the community had to be abandoned because of the official policy of forestland conservation. The response to the F+G treatment showed that this system of bush encroachment management promotes herbaceous species richness (Sawadogo et al., 2005). First, reduced competition from bushy species and increased availability of soil nutrients might have fertilizing effects. Second, fire and grazing could play complementary roles (Fuhlendorf and Engle, 2004). The observed increase in the relative abundance of some species in response to fire and grazing could be interpreted in terms of the removal of old growth and the rejuvenation of disturbance tolerant species. Conversely, the decline of a few species after fire and grazing was probably related to sensitivity to fire damage. The present findings suggest that fire and grazing significantly influenced the relative abundance of most species, probably as a result of increased grazing pressure following fire (Fuhlendorf and Engle, 2004). The findings suggest that fire and grazing could play an important role in maintaining herbaceous species richness and diversity. It was also found that the short-term effects of fire and grazing seem to exert considerable influence on herbaceous biomass and basal cover, which were promoted in the long-term.

The official banning of fire had previously assumed that the use of fire would be damaging to the rangelands. This assumption is not supported when the response of the herbaceous vegetation to fire and grazing is considered in the long-term. Our results suggest that the traditional system is more beneficial from the perspective of biomass production and species diversity, if grazing follows rest after fire. Traditionally, the Borana utilized the burned areas (called *guuba*) after the growth following the early rains and then shifted grazing to older burned areas. Through the rotational use of landscapes with different fire histories (Sheuyange et al., 2005), they maintained the savanna system in productive state.

This demonstration method is widely acceptable to the local communities. It is a system of grazing that can be applied to the wider rangelands without requiring additional labour or other expenses. The difference with our demonstration was that the traditional application of fire was not restricted. Rather, the fire was able to spread beyond the demonstration plots, into those areas where the herders did not intend to burn. Local communities' practices were to protect settlement rangelands from fire in order to conserve fodder for drought periods. In the long-term, the demonstration achieved both conservation of biodiversity and increased biomass production thereby meeting the objectives of the official conservation policy and herder livestock grazing management.

Grazing with bush cover

The current system of range management, in which the use of fire has been banned, promotes bush cover. For the official policymakers, this is the least expensive method of land use, although the exclusion of fire has made the rangelands less productive for the pastoralists in terms of livestock production. The grazing with bush cover system of management showed that herbaceous species richness could be increased. The probable explanation for the addition of new species could be linked to the performance of bush cover tolerant species that were promoted under this demonstration method. An earlier study (Osem et al., 2002) suggested that grazing might favour the recovery of some herbaceous species by suppressing competing species. For example, the observed increase in the relative abundance of a few species under grazing may be attributed to the capacity of individual species to withstand the effect of grazing.

It should be appreciated that bush cover physically constrains livestock grazing, thereby promoting grazing sensitive species that are protected under impenetrable thickets, while in the open areas where the livestock has easier access to grazing, grazing tolerant species were promoted. This means the demonstration might promote two varied populations of grass species; the grazing tolerant and the bush cover tolerant ones. Similarly, previous report (Clarke et al., 2005) indicated a decline in the abundance of herbaceous species under grazing due to selective grazing that promoted disturbance tolerant species over grazing intolerant species. From our results, we inferred that grazing might have negative effects on the relative abundance of some herbaceous species, either in the short- or long-term, depending on the life history of individual species (i.e. annuals and perennials). It was also suggested that grazing can be sustainable on most rangelands, but the long-term effects may lead to the loss of herbaceous species (Fuhlendorf and Engle, 2004). The effect of disturbance such as grazing with bush cover might favour the recovery of some species in the short-term, but in the long-term it may not promote successful establishment. Subsequent failure is probably related to rainfall variability and competition for resources under grazing (Duggin and Gentle, 1998). The significance of the decline in herbaceous biomass may be attributed to the combined effects of grazing pressure and bush cover. Grazing with bush cover reduced the basal cover of herbaceous species, although herbaceous species diversity improved over time.

Tree cutting

The hand clearing of encroached bush should be acceptable to the extension departments, because it treats bush encroachment without introducing fire into the environment. Under the tree cutting method, our results showed an increase in the richness of herbaceous species and the relative abundance of a few of the species among the initial population that were intolerant of bush cover (Dougill and Trodd, 1999). Conversely, a decline in the relative abundance of some herbaceous species in response to tree cutting might reflect shifts in the micro-environment due to the removal of ecologically important trees, thus exposing sensitive species to increased light intensity (particularly for shade loving species). Our results suggest that reduced bush cover could restore herbaceous plant productivity and biodiversity (Bates et al., 2000; Smit, 2004; Ansley and Castellano, 2006). As already indicated, the demonstration method of tree clearing could not be applied to the wider rangelands where bush encroachment is a problem, because of the high costs involved. The local community is more likely to apply this system to local pasture management, such as range enclosures (Angassa and Oba, 2008), as opposed to conducting large-scale land clearing.

CONCLUSIONS

We studied the responses of herbaceous species richness, the relative abundance of species, biomass, basal cover and species diversity in response to different bush encroachment control demonstrations. The results show that protection is comparable to the disturbance demonstrations in terms of herbaceous species richness, while herbaceous biomass accumulation and species diversity were improved by disturbance. Bush encroachment control methods such as tree cutting and fire, tree cutting followed by fire and grazing, and the old traditional method of fire and grazing improved herbaceous biomass, basal cover and diversity, while grazing with bush cover greatly reduced herbaceous biomass. As indicated above, the traditional system of range management is more efficient for improving herbaceous biomass, basal cover and species diversity compared to the current systems of range management imposed on the herders. Thus, future development can use these results to compare benefits in terms of opportunities for the sustainable use of savanna ecosystems and conservation of species diversity in southern Ethiopia. Tree cutting also greatly increased herbaceous biomass and species diversity. Overall, the demonstration methods promoted species richness. The outcomes in terms of herbaceous biomass and the restoration of plant biodiversity in response to the various bush encroachment control treatments have important implications for policy formulation and public education in terms of the future management of savanna ecosystems in southern Ethiopia. By comparing the advantages of various bush encroachment control measures, we conclude that only the fire and grazing method is easy to adopt and reasonable in terms of time and labour required, in order facilitate the control of bush encroachment. The use of fire and grazing seems to be more efficient in promoting forage production, as well as the conservation of biodiversity of herbaceous plants. A bush encroachment control method that promotes forage production and the maintenance of ecosystem diversity, while at the same time is easy to apply is more efficient and has considerable comparative advantages relative to other methods. Defining the comparative advantage of different bush encroachment control methods in terms of forage for livestock and ease of implementation has immediate policy implications. In this regard, priority should be given to the interests of the community rather than focusing on conservation alone. The results of this study clearly show that there is ample scope for policymakers and resource users to improve the management of the savanna ecosystems of southern Ethiopia by focusing on more efficient bush encroachment interventions.

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