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Effects of grazing pressure, age of enclosures and seasonality on bush cover dynamics and vegetation composition in southern Ethiopia

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A B S T R A C T

This study evaluated the dynamics of bush cover in relation to the role played by seasonally grazed traditional enclosures compared to grazed rangelands. The result showed that herbaceous biomass was higher in enclosures than in the open grazed areas. Enclosures also showed more diversity and evenness of herbaceous species than open grazed areas. Herbaceous species richness declined with increased age of enclosures compared to the recent and medium age of enclosures. The frequencies of herbaceous species were relatively similar in both management and across enclosures age. A total of 26 herbaceous and 29 woody species were recorded within both enclosures and open grazed sites. Of the total woody plants, 38% of the species were invasive, while the rest (i.e. 62%) were non-invasive. Generally, grazed areas were less threatened by invasive species than enclosures. The density of invasive woody population (63.4% of the total density of woody population) was 2665 stems ha^{-1}. *Commiphora africana* accounted for most of the increase in cover of woody population, on average contributing 86% to the total invasive woody cover in the study area. A reintroduction of fire is recommended together with the integration of traditional range enclosures in order to control invasion of bush encroachment.

1. Introduction

Increases in the density of woody plants worldwide are a major threat to livestock production (Angassa and Oba, 2008a; Gemedo-Dalle et al., 2006; Oba et al., 2000) and rangeland biodiversity. However, discussions on the mechanisms regulating bush encroachment by invasive woody plants in savanna ecosystems have remained unclear. The dynamics of bush encroachment, which are widespread in African (Oba et al., 2000; Skarpe, 1990a; Van Wijngaarden, 1985), Australian (Burrows et al., 2002), North American and Latin American rangelands (Scholes and Archer, 1997), have been linked to climate change (Archer, 1995) or land use patterns (Angassa and Oba, 2008a) or combination of factors (Oba et al., 2000). The transformation of savanna ecosystems from grassland to woodland may be mediated through fire suppression, heavy grazing and climatic variability. However, the process of bush encroachment in relation to grazing pressure (enclosures vs. open grazed) and time of protection has not been evaluated in the Borana rangelands of southern Ethiopia.

In the Borana rangelands of Ethiopia, bush encroachment has been expanding since the last four decades because of fire suppression and the breakdown of traditional land use practices, expansion of farming in the rangelands, sedentarization and yearly grazing following the creation of permanent water points in the previous wet season grazing rangelands. Long-term prohibition of range fire, cultivation of bottomlands and continuous grazing on the remaining portion of the communal rangelands have induced the invasion of bush encroachment to a level of more than 60% that resulted in reduced grass cover, poor range condition and livestock productivity (Oba, 1998; Oba and Kotile, 2001; Oba et al., 2000). Traditionally, the Borana land use system was based on seasonal grazing strategies between the dry season grazing rangelands that surround the traditional deep well zones and wet season grazing rangelands using rainwater (Oba, 1998). The internal adjustment to diminishing communal resources and breakdown of traditional resource management promoted the establishment of range enclosures. Presently, the growing human and livestock population pressures on the declining communal resources led to the adoption of crop farming and range enclosures for private purposes. In the past three decades, development of water points in terms of semi-permanent ponds has attracted settlements in the rangelands that were traditionally used for wet season grazing. The settlements often carry large populations of livestock (personal observation by

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Ayana Angassa) and the land use around settlements has become intensive. To cope with periodic shortages of forage especially for calves, the local communities of individual settlements established large areas of range enclosures (150–300 ha). At settlement level, seasonal grazing patterns have been developed between the open range during the wet season and enclosures during the dry season. Regardless of the emerging issues of semi-private grazing enclosures in the communal rangelands and subsequent ecological consequences on rangeland diversity, there have not been any studies that investigated the effects of grazing pressure (enclosures vs. open grazed areas), age of enclosures and seasonal grazing patterns on range production and woody plant population dynamics. Range enclosures (*Kalo*) are widely practiced as a semi-private grazing resource by one or more village community members. Range enclosures are rested during the growing season and grazed during the dry season by calves and sick/weak animals for a period of 3–4 months (Coppock, 1994; Oba, 1998; Oba et al., 2001). Oba et al. (2001) suggest that besides preservation of forage for the dry season feeding by calves, enclosures may also be important in the conservation of biodiversity. Earlier research in the northern part of Ethiopia suggests that plant species diversity within enclosures increases with the age of enclosures (Abebe et al., 2006; Mengistu et al., 2005). According to Mengistu et al. (2005), enclosures are among areas with considerable species diversity.

To elucidate the role of traditional range enclosures and the potential mechanisms governing range production and dynamics of invasive woody plants, this study analyzed the effects of grazing pressure, age of enclosures and seasonality on herbaceous biomass, vegetation cover, basal cover of grasses, species richness, density of woody plants, abundance of plant life forms, proportion of individual species and plant species diversity. Therefore, this study was conducted with the aim of identifying the mechanisms of bush encroachment in the Borana rangelands of southern Ethiopia by comparing the effects of enclosures vs. open continuously grazed areas, three age categories of enclosures, as well as seasonal variations on range production and vegetation composition. This was evaluated using a range management system where range enclosures and continuously open grazed areas exhibited different spatial patterns of vegetation dynamics. The specific objectives of the study were: (1) to determine the role of management on herbaceous biomass, abundance, richness and diversity of plant species; (2) to understand the effect of time of establishment (age of enclosures) on herbaceous biomass and abundance, richness, diversity of plant species and vegetation composition; and (3) to evaluate the effects of seasonal variations on range production and vegetation dynamics.

2. Materials and methods

2.1. Study area

The study was conducted on six sites in Dida-Hara (04° 48.663′N and 038° 19.101′E) in the Yabello district, southern Ethiopia. The climate is semi-arid and shows a bimodal type of rainfall, with the long rainy season expected between March and May and the short during October and November. The two intervening dry seasons are from June to August and December to February when forage resources become scarce. Rainfall is variable and spatially distributed with strong effects on range productivity (Oba et al., 2000). The grazing lands of the community in Dida-Hara cover 225 km^2 and about one-third of these grazing areas were occupied by enclosures. Total annual rainfall in 2003 and 2004 was 445 and 427 mm yr^{-1}, respectively (Southern Rangeland Development Unit Meteorology Section, personal communication). Landforms include upland (altitude 1510–1590 m a.s.l.) sandy loam soils and cracking clay soils in bottomlands (Coppock, 1994). *Commiphora* and *Acacia*-species dominate the invasive species.

2.2. Borana traditional system of land use in Dida-Hara

Prior to the 1970s, the rangelands of Dida-Hara (which in the local Oromo dialect means "the plain of the seasonal pond") were open perennial grasslands that were grazed during the wet season and the livestock dispersed in the dry season. Land use includes farmlands and semi-private grazing enclosures and open grazed communal rangelands. The Borana used the communal rangelands for seasonal grazing that involved livestock movements between the wet season and the dry season grazing rangelands (Coppock, 1994). The Dida-Hara rangelands prior to the development of the semi-permanent surface ponds in the 1980s were part of the traditional wet season rangelands exploited by the mobile *fora* herds. The pastoral population is settled in semi-permanent settlements (*Olla*). The livestock population of Dida-Hara is estimated at 21,000 head of cattle, 15,000 small ruminants, 800 camels and 135 equines at a stocking rate of 72 Tropical Livestock Unit km^{-2} (1 TLU = 250 kg bovine) (Ayana Angassa and Gufu Oba, unpublished). Despite the high stocking density, the community adopted semi-private range enclosures in order to cope with periodic feed shortage for vulnerable animal class such as calves.

Prior to the 1970s, the systems of land use involved seasonal grazing and periodic burning of the range. After the 1980s, with the development of perennial ponds, the area was settled and the land use patterns changed from wet season grazing to year-round grazing. Year round intensive grazing combined with change in fire regime led to the conversion of open grasslands into shrub-dominated woodland. For the past four decades long periods of exclusion of range fire combined with heavy grazing of the remaining communal rangelands and establishment of community enclosures altered open savanna grassland to bush dominated rangelands. Presently, the pattern of land use has changed from communal rangelands to semi-private enclosures; at the settlement level, seasonal grazing between the newly established traditional range enclosures and open grazed rangelands was created. As indicated earlier local communities of individual settlements enclosed large areas protected from livestock grazing during the wet season, when the adjacent open grazed rangelands were utilized. The enclosures were grazed by calves during the dry season. Thus, at the settlement level, the seasonal grazing patterns between the open range during the wet season and enclosures during the dry season mimic the traditional wet and dry season rangelands. Calves were allowed to graze inside enclosures during the dry season and shifted to the open grazed rangelands during the wet season. The use of enclosures for grazing during the dry season lasts 3–4 months before the calves were removed following the onset of rains. The open communal rangelands were continuously grazed throughout the year. Since range enclosures were seasonally grazed, they accumulated more herbaceous biomass during the growth season than the open grazed areas.

2.3. Selection of the study sites

The study focused on community-based, semi-private grazing enclosures and adjacent open and grazed settlement rangelands to understand the role played by the traditional range enclosures compared to the open grazed sites of herbaceous biomass production and regeneration potential of invasive woody plants. The selection of enclosures of specific ages involved participation of the local community elders through group discussions at six settlement sites. For each enclosure the adjoining open grazed sites were selected as controls. We grouped the enclosures into three age

Table 1
Results from analysis of variance of the effects of management, age and season on herbaceous vegetation.

Variable	Source	df	*F*	*P*
Biomass	Management	1	148.39	<0.001
	Age	2	1.23	0.295
	Season	2	116.46	<0.001
	Management × season	2	24.31	<0.001
	Age × season	4	2.09	0.083
Basal cover	Management	1	132.18	<0.001
	Age	2	1.96	0.143
	Season	2	11.61	<0.001
	Management × season	2	5.03	0.007
	Age × season	4	0.17	0.954
Species richness	Management	1	17.53	<0.001
	Age	2	0.97	0.382
	Season	2	3.31	0.037
	Management × season	2	0.40	0.668
	Age × season	4	1.66	0.158
Diversity index	Management	1	12.03	0.006
	Age	2	0.75	0.474
	Season	2	5.72	0.004
	Management × season	2	1.73	0.144
	Age × season	4	0.01	0.993
Evenness	Management	1	12.03	0.006
	Age	2	0.75	0.474
	Season	2	5.72	0.004
	Management × season	2	0.01	0.993
	Age × season	4	1.73	0.144

groups: <15 years, 15–25 years, and >25 years. The six sites were arranged along age chronosequence and, therefore, age in this paper is used as an independent variable where each site served as replicates for the enclosure management and the open sites as controls. The enclosures and open grazed sites were located within the same landscape (i.e., in the upland sites).

2.4. Response variables

Vegetation sampling in individual enclosures and the adjacent open grazed areas was conducted in 20 randomly located permanent plots of 1 × 1 m and 5 × 5 m. The 1 m^2 plots were used for sampling herbaceous species and 25 m^2 for sampling woody species. In each age category of the enclosure vs. open grazed areas, the plots of each category were monitored over a period of three seasons; two wet (between November 2003 and May 2004) and one dry (February 2004). Response variables included herbaceous biomass, grass basal cover, species composition, species richness, and density of woody population, species diversity and evenness. Herbaceous biomass was estimated based on the dry matter determination of herbaceous samples. Herbaceous biomass was harvested by hand cutting and samples were oven dried at 65 °C for 48 h. The proportion of grass basal cover was estimated visually based on the area (soil part) covered by a grass base compared to bare ground. Herbaceous biomass and grass basal cover were estimated in plots of 1 m^2. Individual woody species were counted and marked with tree identification numbers to monitor regeneration of invasive woody species in enclosures of different ages and adjacent control treatments. Height measurements were used to categorize woody plants into different size-classes: mature trees (>2 m), saplings (0.5–2 m) and seedlings (<0.5 m). All saplings and seedlings were counted, marked and monitored in enclosures of different age categories compared to the adjacent control treatments. Knowledgeable community members helped with the identification of local plant names. The taxonomic classifications were completed using the herbarium reference of the Southern Rangeland Development Unit (SORDU). We also incorporated the traditional herders' knowledge in the classification of herbaceous species in terms of their response to grazing history (Oba and Kotile, 2001) and woody plants into invasive and non-invasive (Angassa and Oba, 2008b). Shannon diversity index, $H' = -(\sum(pi \ln pi))$ (Shannon, 1948) was determined by calculating the frequency of each plant species (pi = proportion of individual species in each plot at which species i was recorded). Plant species richness (number of species sampled per plot) and evenness of species abundances (Pielou's J index $= H'/\ln S$) were also determined for herbaceous and woody life forms.

2.5. Statistical analysis

The effects of management (enclosures vs. open grazed), the age of the enclosures and seasonality (i.e., independent variables) on herbaceous biomass, grass basal cover, species richness, woody density, species diversity and evenness (dependent variables) were analyzed using the General Linear Model Procedure (SAS Institute, 2001). We compared the spatial and temporal responses of the dependent and independent variables by sites arranged along age chronosequence using a two way ANOVA. The relationships between bush encroachment, herbaceous biomass and species richness of each enclosure age class and open grazed areas were analyzed using the Pearson correlation coefficient. Differences were considered significant at $P < 0.05$.

3. Results

3.1. Effects of management

Herbaceous biomass was significantly (*F*-tests, $P < 0.001$) greater in enclosures than in the open grazed areas (Table 1). Enclosures and open grazed areas disclosed variability in terms of grass basal cover and species richness (*F*-tests, all $P < 0.001$) (Table 1). The diversity index and evenness of herbaceous species were also greater in enclosures than in the open grazed areas (*F*-test, all $P < 0.001$). However, the result showed no significant difference in terms of woody species richness between management (*F*-test, $P > 0.05$) (Table 2). The woody population densities of different age size classes showed variability between management systems (Tables 2 and 3). Similarly, frequencies of common grasses and other herbaceous species varied between the two management systems (Table 4). Overall, equal numbers of herbaceous species (26) in the enclosures and the open grazed areas were recorded (Table 4).

Total woody species (29) in the enclosures was similar to the open grazed sites. The composition of both invasive and non-invasive woody species in the two management systems (enclosures vs. open grazed sites) is given in Table 4. The frequencies of the invasive species such as *Acacia drepanolobium* and *A. bussie* were greatly varied between enclosures and open grazed areas (Table 4). The density of woody plants was 4410 stems ha^{-1} in the enclosures and 3996 stems ha^{-1} in the open sites. Invasive species were accounted for 38% of the total number of woody plants, while the rest (i.e., 62%) were non-invasive (Tables 4–6). The density of invasive woody species was equivalent to a population density of 2665 stems ha^{-1}, while the density of the non-invasive woody plants was 1538 stems ha^{-1}. The density of invasive woody plants in the enclosures (2018 stems ha^{-1}) was greater than in the open grazed sites (647 stems ha^{-1}). Greater density of mature woody population was recorded in the open grazed areas (989 stems ha^{-1}) than in enclosure plots (800 stems ha^{-1}) (*F*-test, $P < 0.01$). The densities of saplings (2209 stems ha^{-1}) (*F*-test, $P < 0.05$) and seedlings (1802 stems ha^{-1}) (*F*-test, $P < 0.001$) in the enclosures were greater than in the open grazed sites that accounted for 1858

Table 2
Results from analysis of variance of the effects of management, age and seasonality on woody vegetation.

Variable	Source	df	F	P
Woody vegetation				
Species richness	Management	1	1.81	0.179
	Age	2	11.69	<0.001
	Season	2	16.16	<0.001
	Management × season	2	0.33	0.719
	Age × season	4	0.00	1.000
Mature tree density	Management	1	7.24	0.008
	Age	2	6.79	0.001
	Season	2	0.31	0.735
	Management × season	2	0.07	0.929
	Age × season	4	0.49	0.745
Saplings density	Management	1	5.73	0.017
	Age	2	25.82	<0.001
	Season	2	0.60	0.549
	Management × season	2	0.01	0.986
	Age × season	4	0.02	0.999
Seedlings density	Management	1	20.18	<0.001
	Age	2	7.12	0.009
	Season	2	32.66	<0.001
	Management × season	2	0.42	0.655
	Age × season	4	0.16	0.959
Diversity index	Management	1	0.63	0.426
	Age	2	6.99	0.001
	Season	2	18.08	<0.001
	Management × season	2	1.26	0.285
	Age × season	4	0.08	0.989
Evenness	Management	1	0.63	0.426
	Age	2	6.99	0.001
	Season	2	18.08	<0.001
	Management × season	2	1.26	0.989
	Age × season	4	0.08	0.285

and 1149 stems ha^{-1}, respectively. *Commiphora africana* accounted for 75% (i.e., 1695 individuals ha^{-1}) of the total population of the invasive woody species recorded both in the enclosures and open grazed sites, while in the open grazed areas it accounted for 25% (i.e., 563 individuals ha^{-1}), suggesting that the mean density of *C. africana* was nearly three times greater in enclosures than in open grazed rangelands (Table 6). Overall, the diversity index and evenness of woody plants were not significantly (F-tests, $P > 0.05$) influenced by management systems. With the exception of mature woody density (differences were significant) the grazed areas were less threatened by invasive species than the enclosures.

3.2. Effects of age

The age of the enclosures had no significant effect on herbaceous biomass, grass basal cover and herbaceous species richness (F-tests all, $P > 0.05$) (Table 1). The result showed that the medium age (i.e., 15–25 years enclosure) accumulated relatively more herbaceous biomass than the younger (<15 years) and older (>25 years) enclosures. The herbaceous species richness declined with increase in age of the enclosures (i.e. <15 years enclosures had more species richness than enclosures of >25 years old). The age of the enclosures had a significant effect on the frequencies of the majority of perennial grass species (F-test, $P < 0.05$) (see also Table 5) but did not influence the diversity index and evenness of herbaceous species (F-tests, all $P > 0.05$) (Table 1).

Woody species richness was significantly (F-test, $P < 0.001$) greater in the younger enclosures than in the older enclosures. Overall, woody plant density was greater in the younger enclosures than in the older (F-test, $P < 0.05$). In terms of age size classes, the densities of mature woody population and saplings were greater in the younger enclosures than in the intermediate, while the density of seedlings was greater in the younger enclosures (<15 years) than in the older enclosures. The diversity and evenness of woody species were greater in the younger enclosures than in the medium and older enclosures. The frequencies of most woody species were greatly different among the three age categories of enclosures with the exception of some non-invasive species such as *Grewia tenax*, *Terminalia browni*, *Balanites aegyptica* and *Euclea shimperi*, and the invasive species such as *A. mellifera*, *C. fluviflora*, *C. africana*, *Cordia gharaf* (Table 5). In all cases we found that the younger enclosures suffered greater regeneration of invasive woody species than the older ones.

3.3. Effects of season

Herbaceous biomass, grass basal cover and species richness significantly (F-test, $P < 0.05$) varied among seasons. The proportion of grass basal cover in the dry season was significantly different compared to the short and main rainy seasons (Table 1). The diversity index and evenness of herbaceous species were also significantly (F-test, all $P < 0.01$) different among seasons. Generally, the composition (i.e. frequencies) of grass species was significantly (F-tests, all $P < 0.05$) different among the three seasons. The lowest proportion of grass basal cover was recorded during the dry season. Interactions between management and season have a significant effect on herbaceous biomass and grass basal cover, while herbaceous species richness, as well as species diversity and evenness were not influenced by season (Table 1).

Mature woody population density and saplings did not significantly (F-tests, all $P < 0.05$) vary with seasons, while woody species richness, seedlings, as well as species diversity and evenness were greatly influenced. The density of seedlings was significantly greater during the main rains than in the other seasons. There was a dramatic increase in the regeneration of woody seedlings from

Table 3
Mean comparison of vegetation attributes in each treatment.

Vegetation variables	Season			Age of enclosures			Management	
	Short rain	Main rain	Dry season	<15 years	15–25 years	>25 years	Enclosure	Grazed
Biomass (g/m^2)	142.3 ± 6.34^b	242.7 ± 6.34^a	123 ± 6.34^c	164.0 ± 6.34^a	176.8 ± 6.34^a	168.1 ± 6.34^a	211.2 ± 5.19^a	128.1 ± 5.19^b
Herbaceous cover (%)	44.3 ± 1.08^a	44.8 ± 1.08^a	43.5 ± 1.08^a	44.1 ± 1.08^a	44.8 ± 1.08^a	43.8 ± 1.08^a	44.2 ± 0.88^a	44.2 ± 0.88^a
Tree cover (%)	57.7 ± 1.03^a	56.5 ± 1.03^a	56.2 ± 1.03^a	56.6 ± 1.03^a	56.7 ± 1.03^a	57.1 ± 1.03^a	56.8 ± 0.84^a	56.8 ± 0.84^a
Basal cover of grasses (%)	14.9 ± 0.51^a	15.8 ± 0.51^a	12.4 ± 0.51^b	13.8 ± 0.51^a	14.1 ± 0.51^a	15.2 ± 0.51^a	17.2 ± 0.42^a	11.0 ± 0.42^b
Density of herbaceous species/m^2	39.5 ± 1.47^b	56.6 ± 1.47^a	37.5 ± 1.47^b	44.0 ± 1.47^{ab}	47.8 ± 1.47^a	41.8 ± 1.47^b	44.6 ± 1.20^a	44.5 ± 1.20^a
Herbaceous richness/m^2	4.6 ± 0.13^b	5.0 ± 0.13^a	4.7 ± 0.13^{ab}	4.6 ± 0.13^a	4.9 ± 0.13^a	4.8 ± 0.13^a	5.1 ± 0.11^a	4.4 ± 0.11^b
Woody richness/25 m^2	3.5 ± 0.15^b	4.5 ± 0.15^a	3.4 ± 0.15^b	4.3 ± 0.15^a	3.3 ± 0.15^b	3.7 ± 0.15^b	3.9 ± 0.12^a	3.7 ± 0.12^a
Density of mature trees/25 m^2	35.1 ± 2.44^a	37.3 ± 2.44^a	34.9 ± 2.44^a	42.1 ± 2.44^a	29.5 ± 2.44^b	35.7 ± 2.44^{ab}	32.0 ± 1.99^b	39.6 ± 1.99^a
Density of saplings/25 m^2	83.9 ± 5.05^a	76.1 ± 5.05^a	83.3 ± 5.05^a	98.1 ± 5.05^a	51.6 ± 5.05^b	94.3 ± 5.05^a	88.4 ± 4.12^a	74.3 ± 4.12^b
Density of seedlings/25 m^2	42.7 ± 5.01^b	92.3 ± 5.01^a	42.1 ± 5.01^b	74.5 ± 5.01^a	50.8 ± 5.01^b	51.7 ± 5.01^b	72.1 ± 4.09^a	46.0 ± 4.09^b

[a,b] Different superscripts within the row show significant difference ($P < 0.05$).

Table 4
Percent composition of individual herbaceous (1 m^{-2}) and woody species (25 m^{-2}) as affected by management (enclosure vs. open grazed).

Species list	Life form	Forage value	Type	Management	
				Enclosure	Open grazed
Aristida adoensis	Grass	Less palatable	Decreasers	1.8	0.8
Bothriochloa radicans	Grass	Highly palatable	Decreasers	0.9	0.5
Brachiaria species	Grass	Palatable	Decreasers	0.3	0.1
Chloris roxburghiana	Grass	Palatable	Decreasers	4.1	3.8
Chrysopogon aucheri	Grass	Palatable	Decreasers	28.4	18.7
Cenchrus ciliaris	Grass	Highly palatable	Decreasers	3.0	3.3
Cyprus species	Sedges	Palatable	Decreasers	0.1	0.1
Dactyloctenium aegyptium	Grass	Palatable	Decreasers	0.1	0.1
Digitaria milanjiana	Grass	Highly palatable	Decreasers	0.2	0.3
Echinochloa haploclada	Grass	Less palatable	Increasers	0.1	0.1
Eleusine jaegeri	Grass	Unpalatable	Increasers	1.0	1.6
Eragrostis papposa	Grass	Palatable	Increasers	1.3	2.4
Eragrostis senni	Grass	Unidentified	Decreasers	0.2	0.1
Enteropogon somalensis	Grass	Less palatable	Decreasers	0.1	0.1
Harpachne schimperi	Grass	Unpalatable	Decreasers	0.2	0.1
Heteropogon contortus	Grass	Highly palatable	Decreasers	4.6	1.4
Hyparrhenia hirta	Grass	Less palatable	Decreasers	0.1	0.1
Lintonia nutans	Grass	Palatable	Increasers	1.2	3.5
Leptothrium senegalensis	Grass	Palatable	Increasers	4.4	14.7
Panicum coloratum	Grass	Highly palatable	Increasers	7.7	18.6
Panicum maximum	Grass	Palatable	Decreasers	0.1	0.1
Panicum turgidum	Grass	Less palatable	Decreasers	2.5	1.0
Pennisetum stramineum	Grass	Less palatable	Increasers	0.1	0.1
Sporobolus pyramidalis	Grass	Less palatable	Decreasers	25.2	15.8
Themeda triandra	Grass	Less palatable	Decreasers	5.3	1.1
Other herbaceous species	Forbs	Unpalatable	Increasers	7.8	13.3
Acacia brevispica	Shrub	Palatable	Invasive	1.0	0.3
Acacia drepanolobium	Tree	Unpalatable	Invasive	3.1	0.6
Acacia etbaica	Tree	Unpalatable	Invasive	3.2	1.9
Acacia nilotica	Tree	Palatable	Non-invasive	7.3	4.9
Acacia seyal	Tree	Palatable	Invasive	1.5	0.9
Acacia tortilis	Tree	Palatable	Non-invasive	6.5	1.5
Acacia bussie	Tree	Palatable	Invasive	0.7	2.2
Acacia goetzei	Tree	Unidentified	Non-invasive	0.4	0.1
Acacia mellifera	Tree	Unpalatable	Invasive	0.1	0.1
Grewia tenax	Shrub	Palatable	Non-invasive	4.0	3.3
Boscia coriacea	Tree	Unidentified	Non-invasive	1.1	1.2
Grewia villosa	Shrub	Unidentified	Non-invasive	0.9	0.1
Grewia bicolor	Shrub	Palatable	Non-invasive	0.7	1.0
Commiphora campestis	Shrub	Unidentified	Invasive	1.1	1.0
Acacia senegal	Tree	Unidentified	Non-invasive	1.3	2.9
Ormocarpum mimosoides	Shrub	Unpalatable	Non-invasive	1.5	3.6
Lannea floccose	Tree	Palatable	Non-invasive	7.8	5.0
Commiphora fluviflora	Shrub	Palatable	Invasive	0.6	0.7
Commiphora crenulata	Shrub	Palatable	Invasive	0.3	0.1
Rhus natalensis	Tree	Palatable	Non-invasive	0.5	0.5
Comiphora africana	Shrub	Palatable	Invasive	56.2	53.9
Euclea shimperi	Shrub	Unidentified	Non-invasive	0.2	0.1
Combretum molle	Tree	Unidentified	Non-invasive	0.1	0.6
Terminalia brownii	Tree	Unidentified	Non-invasive	0.1	0.4
Boswellia hildebrantii	Tree	Palatable	Non-invasive	0.1	0.2
Dichrostachys cinerea	Tree	Unidentified	Non-invasive	0.1	0.5
Acacia elatior	Tree	Palatable	Non-invasive	0.1	0.6
Cordia gharaf	Shrub	Palatable	Invasive	0.2	0.1
Balanites aegyptica	Tree	Palatable	Non-invasive	0.1	0.1

1053 individuals ha^{-1} (in the dry season) to 2306 individuals ha^{-1} (in the main rainy season). The increase in the proportion of woody seedling density between the dry season and main rainy season was 54%, while between the dry and short rainy season the increase was only 1.2%. Among the woody species only *C. africana* greatly responded to seasonal variability. In general, seasonal variability had a significant influence on the diversity of woody species with the highest species diversity index recorded in the main rainy season.

Interactions between age and season have no significant (*F*-tests, all $P > 0.05$) effect on any of the response variables. In general, Pearson's correlation between herbaceous biomass and woody population density was positive and highly significant ($r = 0.23$, $P < 0.001$), compared to the relation between woody population and herbaceous species richness ($r = 0.040$, $P = 0.451$). Generally, woody plants and grass basal cover showed no significant relationships ($r = -0.042$, $P = 0.428$) (Table 7). Overall, the correlation between vegetation variables in terms of age of enclosures and adjacent open grazed areas is summarized and presented in Table 7.

4. Discussion

4.1. Effects of management

With decreased grazing pressure in enclosures, herbaceous biomass, grass basal cover and richness were increased, suggesting

Table 5
Effect of enclosures age on percent composition of individual herbaceous species (1 m^{-2}) and woody species (25 m^{-2}).

Species list	Life form	Forage value	Type	Age of enclosures		
				<15 years	15–25 years	>25 years
Aristida adoensis	Grass	Less palatable	Decreasers	2.2	0.9	0.6
Bothriochloa radicans	Grass	Highly palatable	Decreasers	1.0	0.1	1.1
Brachiaria species	Grass	Palatable	Decreasers	0.1	0.1	0.1
Chloris roxburghiana	Grass	Palatable	Decreasers	6.4	0.8	4.5
Chrysopogon aucheri	Grass	Palatable	Decreasers	24.2	29.4	16.5
Cenchrus ciliaris	Grass	Highly palatable	Decreasers	3.48	2.3	3.7
Cyprus species	Sedges	Palatable	Decreasers	0.1	0.1	0.1
Dactyloctenium aegyptium	Grass	Palatable	Decreasers	0.1	0.1	0.1
Digitaria milanjiana	Grass	Highly palatable	Decreasers	0.5	0.1	0.1
Echinochloa species	Grass	Less palatable	Increasers	0.1	0.1	0.1
Eleusine jaegeri	Grass	Unpalatable	Increasers	0.1	2.2	0.4
Eragrostis papposa	Grass	Palatable	Increasers	0.9	2.3	2.5
Eragrostis senni	Grass	Unidentified	Decreasers	0.1	0.2	0.2
Enteropogon somalensis	Grass	Less palatable	Decreasers	0.1	0.1	0.1
Harpachne schimperi	Grass	Unpalatable	Decreasers	0.3	0.1	0.2
Heteropogon contortus	Grass	Highly palatable	Decreasers	4.1	3.1	1.6
Hyparrhenia hirta	Grass	Less palatable	Decreasers	0.1	0.1	0.1
Lintonia nutans	Grass	Palatable	Increasers	1.4	3.0	2.8
Leptothrium senegalensis	Grass	Palatable	Increasers	8.4	4.0	16.9
Panicum coloratum	Grass	Highly palatable	Increasers	7.8	9.3	22.8
Panicum maximum	Grass	Palatable	Decreasers	0.1	0.1	0.1
Panicum turgidum	Grass	Less palatable	Decreasers	3.2	1.3	0.7
Pennisetum stramineum	Grass	Less palatable	Increasers	0.2	0.1	0.1
Sporobolus pyramidalis	Grass	Less palatable	Decreasers	20.0	25.4	15.3
Themeda triandra	Grass	Less palatable	Decreasers	4.0	3.5	1.7
Other herbaceous species	Forbs	Unpalatable	Increasers	11.7	12.0	8.4
Acacia brevispica	Shrub	Palatable	Invasive	2.5	0.1	0.1
Acacia drepanolobium	Tree	Unpalatable	Invasive	0.2	3.9	0.1
Acacia etbaica	Tree	Unpalatable	Invasive	2.8	0.4	5.2
Acacia nilotica	Tree	Palatable	Non-invasive	3.9	10.6	3.3
Acacia seyal	Tree	Palatable	Invasive	2.8	1.2	0.2
Acacia tortilis	Tree	Palatable	Non-invasive	5.3	16.0	8.6
Acacia bussie	Tree	Palatable	Invasive	2.5	0.1	2.8
Acacia goetzei	Tree	Unidentified	Non-invasive	1.1	0.1	0.1
Acacia mellifera	Tree	Unpalatable	Invasive	0.2	0.1	0.1
Grewia tenax	Shrub	Palatable	Non-invasive	3.7	4.4	3.1
Boscia coriacea	Tree	Unidentified	Non-invasive	0.5	0.8	2.2
Grewia villosa	Shrub	Unidentified	Non-invasive	0.2	0.1	1.1
Grewia bicolor	Shrub	Palatable	Non-invasive	1.8	0.2	0.9
Commiphora campestis	Shrub	Unidentified	Invasive	0.4	1.9	0.7
Acacia senegal	Tree	Unidentified	Non-invasive	3.6	0.8	2.7
Ormocarpum mimosoides	Shrub	Unpalatable	Non-invasive	0.4	2.9	4.2
Lannea floccose	Tree	Palatable	Non-invasive	6.3	8.3	5.1
Commiphora fluviflora	Shrub	Palatable	Invasive	0.5	0.6	0.9
Commiphora crenulata	Shrub	Palatable	Invasive	0.1	0.4	0.1
Rhus natalensis	Tree	Palatable	Non-invasive	1.1	0.6	0.1
Commiphora africana	Shrub	Palatable	Invasive	55.7	46.6	59.4
Euclea shimperi	Shrub	Unidentified	Non-invasive	0.3	0.1	0.1
Combretum molle	Tree	Unidentified	Non-invasive	1.1	0.1	0.1
Terminalia brownii	Tree	Unidentified	Non-invasive	0.7	0.1	0.1
Boswellia hildebrantii	Tree	Palatable	Non-invasive	0.3	0.1	0.1
Dichrostachys cinerea	Tree	Unidentified	Non-invasive	1.0	0.1	0.1
Acacia elatior	Tree	Palatable	Non-invasive	1.2	0.1	0.1
Cordia gharaf	Shrub	Palatable	Invasive	0.1	0.2	0.1
Balanites aegyptica	Tree	Palatable	Non-invasive	0.1	0.1	0.1

that enclosures may be more important in promoting range productivity and conservation of biodiversity. It seems that grazing by livestock has a major influence in determining herbaceous biomass and grass basal cover in the open grazed areas compared to the enclosures. Previous study (e.g., Tadesse et al., 2002) in the west central part of Ethiopia has indicated that the biomass within enclosures was higher than open grazed plots. The differences observed in herbaceous biomass, grass basal cover and richness, herbaceous diversity index and evenness between the enclosures and open grazed areas in the current study were comparable with the work done by Oba et al. (2001) in northern Kenya and Lenzi-Grillini et al. (1996) in the Queen Elizabeth National Park in Uganda. Similar findings have been reported in the Kondoa region in Tanzania (e.g., Mwalyosi, 2000), and central and northern Ethiopia (Asefa et al., 2003; Mengistu et al., 2005) that showed that the increase in herbaceous biomass in enclosures could be linked with reduced grazing disturbance by livestock. Rosenstock (1996) reported the opposite, suggesting that biomass was not affected by rest from grazing. Hayashi (1996) in Kitui area in Kenya reported that exclusion of livestock grazing for a period of 5 years promoted herbaceous cover compared to open grazed areas. The current study showed that enclosures promoted herbaceous species richness. The results of our study were comparable with the findings of Hiernaux (1998) in the rangelands of Sahel and Rosenstock (1996) in a semi-arid shrub grassland habitat of south-central Utah that reported that protection from grazing increased flora richness and

Table 6
The effect of management (enclosures compared to adjacent open grazed sites) on the population structure of invasive and non-invasive woody plants (plants ha^{-1}).

Invasive woody species	Type	Enclosure	Open
Acacia brevispica	I	26	3
Acacia drepanolobium	I	50	6
Acacia etbaica	I	81	20
Acacia seyal	I	43	10
Acacia bussie	I	53	23
Acacia mellifera	I	3	1
Commiphora campestis	I	34	11
Commiphora fluviflora	I	22	8
Commiphora crenulata	I	7	1
Comiphora africana	I	1695	563
Cordia gharaf	I	5	1
Acacia nilotica	NI	241	196
Acacia tortilis	NI	478	544
Acacia goetzei	NI	52	7
Grewia tenax	NI	160	133
Boscia coriacea	NI	52	48
Grewia villosa	NI	21	2
Grewia bicolor	NI	46	40
Acacia senegal	NI	110	115
Ormocarpum mimosoides	NI	108	143
Lannea floccose	NI	278	203
Rhus natalensis	NI	25	20
Euclea shimperi	NI	7	2
Combretum molle	NI	19	23
Terminalia brownii	NI	12	15
Boswellia hildebrantii	NI	6	6
Dichrostachys cinerea	NI	17	18
Acacia elatior	NI	20	25
Balanites aegyptica	NI	2	2

I, invasive; NI, non-invasive.

Table 7
Pearson correlation matrix and *P*-values in enclosures of different ages and adjacent open sites, in Borana, southern Ethiopia.

Age of enclosures and adjacent open sites vs. vegetation variables	*r*	*P*
Herbaceous biomass vs. woody density		
<15 years	0.01	0.930
15–25 years	0.02	0.889
>25 years	0.01	0.928
Open site	−0.09	0.216
Woody density vs. herbaceous richness		
<15 years	−0.14	0.298
15–25 years	−0.03	0.820
>25 years	0.25	0.057
Open site	0.04	0.624
Woody density vs. grass basal cover		
<15 years	−0.24	0.065
15–25 years	−0.14	0.271
>25 years	0.08	0.573
Open site	−0.25	0.001
Grass basal cover vs. herbaceous biomass		
<15 years	0.08	0.573
15–25 years	0.39	0.002
>25 years	0.36	0.005
Open site	0.34	<0.001

perennial grass cover. Oba et al. (2001) in northern Kenya reported that the decline in species richness at a high biomass level is a major concern for rangeland conservation and management. The current study found that herbaceous species diversity increased with reduced grazing pressure in enclosures compared with open grazed areas. Others have reported similar patterns (Asefa et al., 2003; Mengistu et al., 2005), suggesting that area enclosures build up more diversity of plant species relative to open grazed areas. The decline in herbaceous biomass with increased trends of grazing pressure in the open grazed sites and dry season largely related to both the effects of grazing pressure and seasonal variability.

In the present study, as we expected, our results show that the regeneration potential of saplings and seedlings was greater than mature woody density in both enclosures and open grazed areas, suggesting that the increased density of bush encroachment was a major threat in the savannas of southern Ethiopia. Increases in the density of bush cover have been documented in southern Ethiopia rangelands (Angassa and Baars, 2000; Angassa and Oba, 2008a; Bille and Eshete, 1983; Coppock, 1994; Eshete et al., 1986; Gemedo-Dalle et al., 2006; Oba et al., 2000; Tamene, 1990). Comparison of our results between the two management systems indicates that enclosures had more sapling and seedling densities than open sites. Smart et al. (1985) in Murchison Falls National Park in Uganda showed that long-term exclusion of grazing resulted in an increase of woody plant species. A study conducted in Kenya reports greater density of shrubs in the enclosure than in the open grazed areas (Hayashi, 1996). Similar evidences from different parts of the world (e.g., Andersen and Holte, 1981; Augustine and McNaughton, 2004; Eccard et al., 2000; Lenzi-Grillini et al., 1996; Rosenstock, 1996) also showed that absence of livestock grazing results in marked regeneration and higher density of woody layer. Re-establishment of dense woody layer was reported by Western and Maitumo (2004) following a 20-year exclusion of herbivore grazing in the Amboseli National Park in Kenya. The same authors indicated that exclusion of herbivores promotes woody seedling establishment. A study carried out on the Wyoming sagebrush steppe reports a greater density of shrub cover inside enclosure than outside as a result of long-term exclusion of livestock from only one of the nine enclosures (Muscha et al., 2004). However, the present finding differed from earlier studies by Skarpe (1990a,b), and Trodd and Dougill (1998), suggesting that shrub density increased with heavy grazing. Our data showed that invasive woody species contributed a greater (63.4%) proportion to woody population density compared to the non-invasive species. Similarly, enclosures had more invasive woody species than open grazed sites probably as a result of rest from grazing and more regeneration of seedlings and saplings. Although *C. africana* singularly contributed to the population structure of invasive woody plants both inside and outside enclosures than other species. With reduced disturbance inside enclosures, the study found greater regeneration potential of invasive woody population, suggesting that grazing alone is not a major factor for the expansion of bush encroachment. It seems that heavy grazing outside enclosures may reduce grass competition and fire frequencies. It also seems that the presence of browsers may influence survival of tree seedlings in the open grazed areas (e.g., Chauchard et al., 2006), while lack of browsing animals such as camels and goats inside enclosures probably lead to the increased density of bush cover (Angassa and Oba, 2008a). A lower regeneration potential of woody population density in the open grazed areas at high grazing pressure implied that other environmental factors (e.g., the ban on fire and climate change) might influence the population structure of woody plants than the effect of grazing. In general, our results confirmed that the regeneration potential of invasive woody plants was not promoted by heavy grazing alone. Mwalyosi (2000) in the Kondoa region in Tanzania showed a similar pattern, suggesting that shrubs and trees had greater species frequencies inside than outside the enclosure. Eccard et al. (2000) in the semi-arid Karoo in South Africa indicated that shrubs of 1–2 m height were abundant in enclosures and missing completely in the adjacent open sites. Although the driving forces behind the dynamics of bush cover are not clear, the fact that woody species richness and the diversity index showed no variation between the different management approaches provides a good evidence to support the prediction that in a highly variable ecosystem, grazing might have limited effect in driving bush encroachment.

The results of our findings suggest that grazing alone did not increase the density of bush encroachment. Previous studies (e.g., Coppock, 1993, 1994; Dyksterhuis, 1949) argued that as grazing pressure increases, range condition declines through successional trends by invasion of bush encroachment. However, greater density of mature woody population in the open grazed areas might be due to the long-term effect of grazing combined with other environmental factors (Gillson, 2004) or probably the effect of management measures in enclosures in an attempt to control bush encroachment by the local community such as selective hand clearing of mature woody population. The lack of significant effects between management systems for some of the response variables might suggest that there are other additional factors behind the mechanisms of bush encroachment besides the effect of heavy grazing.

4.2. Effects of age

The results of our findings indicate that the age of the enclosure had no significant effect on herbaceous biomass, grass basal cover and richness. Previously published work in the highlands of Bolivia (e.g., Buttolph and Coppock, 2004) showed a similar pattern, suggesting that variation in years of enclosures showed no significant effect on aboveground biomass. However, our findings confirmed that herbaceous species richness declined with an increase in age of the enclosures. Our data showed a similar pattern with earlier studies conducted elsewhere in East Africa (Asefa et al., 2003; Oba et al., 2001), Sahel rangelands (Hiernaux, 1998) and in the Inner Mongolia Autonomous region, northern China (Zhang et al., 2005) suggested that short-term exclusion promoted herbaceous species richness, while long-term resting was not beneficial. Zhang et al. (2005), for example, reported that the number of species increased from 7 to 17 in the 6-year enclosure and 10-year, respectively, while it declined to 14 in the 18-year enclosure, while Hiernaux (1998) reported greater plant species richness in the 3-year-old than in the 14-year-old enclosure. The younger enclosure had a lower proportion of grass basal cover than the other older enclosures, which could be attributed to a greater density of woody species in the younger enclosure. This agrees with previous research results conducted in southern Ethiopia (Oba et al., 2000) and in northeastern Namibia (Sheuyange et al., 2005), suggesting that the invasion of bush encroachment reduces grass cover.

We expected that the regeneration potential of invasive woody population, richness and the diversity index would change with the older age of enclosures probably due to protection from grazing in response to successional trends. The findings of our result showed that the expectation that responses of invasive woody plant density, species richness and diversity to the age of the enclosures increased with the older enclosures, were not confirmed. Contrary to our expectation, bush invasion was greater in the younger than in the older enclosures. Increased density of woody population in the younger enclosure indicates that neither grazing nor long-term resting promote bush encroachment. Greater density of invasive woody species in the younger enclosures than in the older enclosures would suggest that the woody plants were probably thinned by selective hand removal by the local community. Conversely, in the younger enclosure improved growth conditions and protection from browsing animals probably promoted the regeneration of invasive woody species.

4.3. Effects of season

Seasonal variation considerably influenced herbaceous biomass, grass basal cover and richness, as well as diversity and evenness of herbaceous species. The main rainy season had significantly greater grass basal cover than the dry season. Our results are in accordance with the findings of previous research (Fernandez-Gimenez and Allen-Diaz, 1999; Fynn and O'Connor, 2000; O'Connor, 1995, 1994), suggesting that variation in rainfall greatly influenced biomass and species composition. It has also been reported that the dynamics of arid and semi-arid rangelands are prone to the effect of rainfall (Illius and O'Connor, 1999). A significant variation in herbaceous biomass during the different seasons in both management systems suggested that seasonal variation was an important factor in regulating biomass in arid and semi-arid environments.

Interaction between management and seasonality influenced herbaceous biomass and grass basal cover. The results of our data were comparable with the report of O'Connor and Roux (1995) in the Karoo region in South Africa, suggesting that plant basal area was more strongly influenced by rainfall variability. The decline in grass basal cover in the open grazed areas could be due to the interaction between management and seasonality. In the dry season, enclosures had greater proportions of grass basal cover (14%) than open grazed areas (11%), while in the main rainy season, the proportion of grass basal cover increased from 14 to 20% in the enclosure plots and from 11 to 12% in the open grazed areas.

Our results suggest that seasonality greatly influenced woody species richness, seedling density, diversity and evenness of woody plants, while the densities of mature woody plants and saplings were not influenced. Seasonality also greatly influenced the density of woody plant seedlings. The variation in the regeneration potential of invasive woody species among seasons suggests that in arid and semi-arid environments, variation in rainfall might influence the structure of invasive woody plants more than did the effect of grazing. O'Connor (1994) reported a similar pattern in Southern Africa, suggesting that the changes in plant species density could be attributed to rainfall variability than grazing. However, Fernandez-Gimenez and Allen-Diaz (1999) argued that grazing pressure may also be a major factor in regulating vegetation productivity and composition in more stable environments. Interactions between management and seasonality would probably influence bush cover dynamics, with a rainy season resulting in greater regeneration potential of invasive woody population than the dry season. The observation made in this study corresponds with earlier studies (Fernandez-Gimenez and Allen-Diaz, 1999; Jeltsch et al., 1997; O'Connor and Roux, 1995), suggesting that seasonality influenced the regeneration potential of invasive woody species. Others have found that some ecosystems show no significant effect between years of vegetation cover in response to variation in rainfall (Allen-Diaz and Jackson, 2000; Fernandez-Gimenez and Allen-Diaz, 1999). In general, vegetation cover was slightly higher in the main rainy season than in the dry season in both enclosures and open grazed areas, suggesting that vegetation cover is responsive to variations in rainfall. In the majority of the cases, the response variables were significantly different among seasons suggesting that seasonality is a major factor in driving vegetation dynamics in the savannas of southern Ethiopia. Although the short-term duration of our experiment could be a significant limitation to conclude about the mechanisms behind bush encroachment in the savannas of southern Ethiopia, the use of enclosures along age chronosequence in the same landscape and the similarity of the environment imply that grazing alone is not a major factor in driving bush encroachment. We expected that the regeneration of invasive woody species, richness and diversity could be more affected by season, interactions between management and seasonality, as well as interactions between the age of the enclosures and seasonality. Seasonality influenced woody species richness, seedling density, and the diversity index and evenness. However, the response of sapling and mature woody densities did not vary significantly with the interactions of management and seasonality, as well as age and season as we expected, suggesting that clear trends are lacking in the dynamics of invasive woody plants in terms of management or age of enclosures but related to seasonality. Our results support the assumption that vegetation dynamics in arid environments are controlled by a combination of factors (Ellis and Swift, 1988), but not necessarily directly related to grazing intensity. The present study shows that range production and vegetation composition are largely shaped by seasonal variability combined with grazing pressure. The implication of the present finding was that grazing pressure alone is inadequate to describe the driving forces behind bush encroachment without considering the roles of seasonality and other environmental factors (Biot, 1993; Oba et al., 2001).

5. Conclusion and management implications

Establishment of traditional range enclosures in the settled areas of southern Ethiopia is the communities' responses to declining grazing resources. At the settlement level, pastoralists adopted different land use systems based on rotational grazing alternating between enclosures and the open communal rangelands during different seasons of the year. The effect of management on biomass was substantial. However, bush encroachment is not attributed to heavy grazing alone. Most of the response variables with management and age of the enclosures were strongly influenced by seasonality, a characteristic of arid and semi-arid environments. In combination with seasonality, the ban on fire and exclusion of browsing animals such as goats and camels may also contributed to the invasion of bush encroachment. In determining the direction of pastoral development and making decisions as the basis for management in the savannas of southern Ethiopia, knowledge of rangeland vegetation dynamics is crucial. The role played by traditional enclosures in controlling the invasion of bush encroachment could be better explained if management is linked to bush clearing and the use of fire followed by browsing animals. Enclosures had more accumulation of biomass than that of outside enclosures and could be linked to bush clearing and the use of fire as future range management plan at the settlement level through the participation of local communities. Hence, a future bush control program should be integrated with enclosures where biomass accumulation is favorable in facilitating range burning for the improvement of pasture condition. Our findings have implications for traditional ways of range management in southern Ethiopia, where the customary land use practices in response to seasonality in terms of biomass allows migratory and opportunistic use of available resources in time and space. From our results we conclude that enclosures promote the regeneration of invasive woody plants, but no evidence was found on the interaction between management and seasonality, or age of enclosures and seasonality in promoting bush encroachment. We recommend the combined use bush clearing and fire followed by browsers in the management of rangelands in southern Ethiopia that must be integrated with enclosures in order to control the invasion of bush encroachment.

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