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Changes in woody species composition following establishing exclosures on grazing lands in the lowlands of Northern Ethiopia

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Restoring vegetation in low rainfall areas is difficult and urges the need to design an effective and low-cost method of vegetation restoration. This study was undertaken in the lowlands of northern Ethiopia to: (1) investigate how exclosure age affects restoration of degraded native plant species richness, diversity and aboveground standing biomass, and (2) identify soil characteristics, which affect effectiveness of exclosures to restore degraded native vegetation. Replicated (n = 3) 5-, 10- and 15-year-old exclosures were selected and each exclosure was paired with an adjacent grazing land to detect changes in vegetation variables following establishing exclosures on communal grazing lands. All exclosures displayed higher species richness, diversity and aboveground biomass when compared to the adjacent grazing lands. Results on vegetation composition indicate that all exclosures are at early stage of succession. In all exclosures and grazing lands, vegetation variables displayed significant ($p < 0.05$) correlations with soil variables indicating that consideration of soil fertility will help enhance natural regeneration in exclosures. Our study indicates that the establishment of exclosures on degraded communal grazing lands can be effective in restoring degraded native vegetations, and with time, exclosures may obtain an important role as source of seeds of indigenous woody species.

Key words: Grazing pressure, land degradation, land use conversion, native vegetation, soil variables, vegetation restoration.

INTRODUCTION

Degradation of vegetation has eventually led to desertification in Africa than any other continent (FAO, 2001). A total of 340 million ha of woody vegetation in dryland zones of Africa have become degraded through human activities (FAO, 2001). The dryland vegetation in Ethiopia resides in arid and semi-arid lands, which occupy 50% of the land area (Jama and Zeila, 2005) and comprise the largest vegetation resource of the country (Mengistu et al., 2005). At present, this dryland vegetation is facing intense degradation as a consequence of deforestation, agricultural land expansion and overgrazing (Lemenih et al., 2005; Mengistu et al., 2005). This in turn affects the productivity and diversity of forest, woodland and bushland resources. Counteracting the degradation of vegetation by rehabilitating degraded dryland forests is one of the central concerns of the government and local communities in Ethiopia (Girma, 2001; Kebrom, 2001).

In Tigray, northern Ethiopia, communities and local authorities started to establish exclosures to rehabilitate degraded communal grazing lands about three decades ago. Exclosures are areas closed from the interference of human and domestic animals with the goal of promoting natural regeneration of plants and reducing land degrada-

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tion of formerly degraded communal grazing lands (Mekuria et al., 2011). Exclosures are usually established in steep, eroded and degraded areas which have been used for grazing in the past (Descheemaeker et al., 2006). The inception of exclosures dates back to the 1980’s and coincided with the large-scale land rehabilitation and soil and water conservation programs in Ethiopia (Nedessa et al., 2005). Exclosure management and protection have proven to be effective because of the participation of the local communities in the establishment of exclosures and the responsibility of local authorities for management and protection of the area (Descheemaeker et al., 2006). Following establishment, the vegetation recovery process in exclosures consistently starts with the rapid recovery of herbaceous species (that is, including grasses). After three to five years, shrub and tree species gain importance and suppress the abundance of herbaceous species (Assefa et al., 2003).

Several case studies conducted in the central and northern highlands (e.g. Mengistu et al., 2005; Yami et al., 2006; Berhane et al., 2007; Yayneshet et al., 2009) and southern lowlands (Angassa and Oba, 2010) of Ethiopia have shown that exclosures can be effective in enhancing composition, diversity, and density of vegetation. However, exclosures can also have negative impacts such as causing shortage of fuel wood and increasing grazing pressure on the remaining communal grazing areas (Mekuria et al., 2011). Therefore, it is important to make a careful evaluation of the benefits and costs of exclosure establishment (Descheemaeker et al., 2006). One important aspect in evaluating plans for establishing additional exclosures on communal grazing lands is the potential of exclosures for vegetation restoration.

Although exclosures have been established in the northern lowlands of Ethiopia for about three decades, empirical data on the effectiveness of these protected areas in restoring vegetation are lacking. Particularly, predictive relationships among vegetation composition, exclosure age, and soil factors that control the restoration of native vegetation have not been explored well. This information is critical, however, for evaluation of existing exclosures in restoring degraded native vegetation and for deciding whether additional exclosures should be established. In addition, land managers working in the northern lowlands of Ethiopia at local level are facing challenges to base their decision on scientific information due to lack of studies. This in turn urges the need to explore the effectiveness of exclosures in restoring degraded native vegetation and the controlling factors under existing biophysical and socio-economic conditions of the northern lowland of Ethiopia, and support local land managers in their decision by generating empirical data.

The study was carried out in the northern lowlands of Ethiopia with the following objectives: (1) to investigate how exclosure age affects restoration of degraded native plant species richness, diversity and aboveground standing biomass, and (2) to identify soil characteristics influencing the effectiveness of exclosures in restoring degraded native vegetation. Based on a review of more than 15 existing case studies (e.g., Smit et al., 1999; Assefa et al., 2003; Osem et al., 2002, 2004; Mengistu et al., 2005; Abebe et al., 2006; Yami et al., 2006; Berhane et al., 2007; Muchiru et al., 2009; Yayneshet et al., 2009; Hosseinzadeh et al., 2010; Verdoodt et al., 2010) and their findings related to changes in vegetation composition following establishing exclosures and the controlling factors, we formulated the following hypotheses: (1) after establishing exclosures on communal grazing lands, recovery of plant species richness will be moderated by soil fertility, where we expect a higher species richness and diversity in relatively fertile sites as our study sites are degraded, (2) the composition of naturally regenerated plant species will be dominated by herbaceous species in the younger exclosures and shrub and tree species in the older exclosures, (3) aboveground biomass will be improved after establishing exclosures on communal grazing lands, and (4) the older exclosures will have comparable species composition with the surrounding church forests. The analyzed plant species richness, diversity, density, and aboveground biomass from exclosures were compared with those of adjacent communal grazing lands. The trends in the changes were then used as indicators of exclosure effectiveness to restore degraded vegetation.

METHODS

Study area

The study was carried out in three districts of Tigray (12° - 15° N latitude and 36° 30' - 40° 30' E longitude), the northernmost region of Ethiopia (Figure 1, Table 1). All sites have a tropical, semi-arid climate. Mean annual rainfall (for the years 2000 to 2006) varied between 488 and 645 mm $year^{-1}$ with an average of 562 mm $year^{-1}$. Mean minimum temperature ranged from 11 to 17°C and mean maximum temperature ranged from 26 to 34°C (Ethiopian Meteorological Service Agency, 2007). The rainy season usually occurs between June and September with the growing period of 60 to 90 days. According to the district Agricultural and Rural Development Office, average farm size ranges from 0.75 to 2.5 ha per household.

Soils of the study sites were classified into three major groups: Leptosol, Regosols, and Cambisols (WRB, 2006; Table 1). The most common woody vegetation species included *Acacia seyal*, *Acacia melifera, Acacia etbaica,* and *Balanites aegyptiaca.* Diverse assemblages of grasses and herbs dominated the under-storey vegetation.

According to the districts Agricultural and Rural Development offices, major land uses at the study sites included cultivated lands (between 24 and 62% of the area), forest lands (0 to 14%), exclosures (6 to 21%), grazing lands (2 to 18%) and others (1 to 30%). Mixed crop-livestock farming is the backbone of households’ livelihoods in all of the study sites. Major cultivated crops include *Zea mays* (maize), *Eragrostis teff* (teff), *Sorghum bicolour* (sorghum), and *Arachis hypogea* (peanut).

In the study areas, the first exclosures were established two decades ago and accordingly we selected replicated (n = 3) exclosures of 5, 10 and 15 years which are paired with adjacent

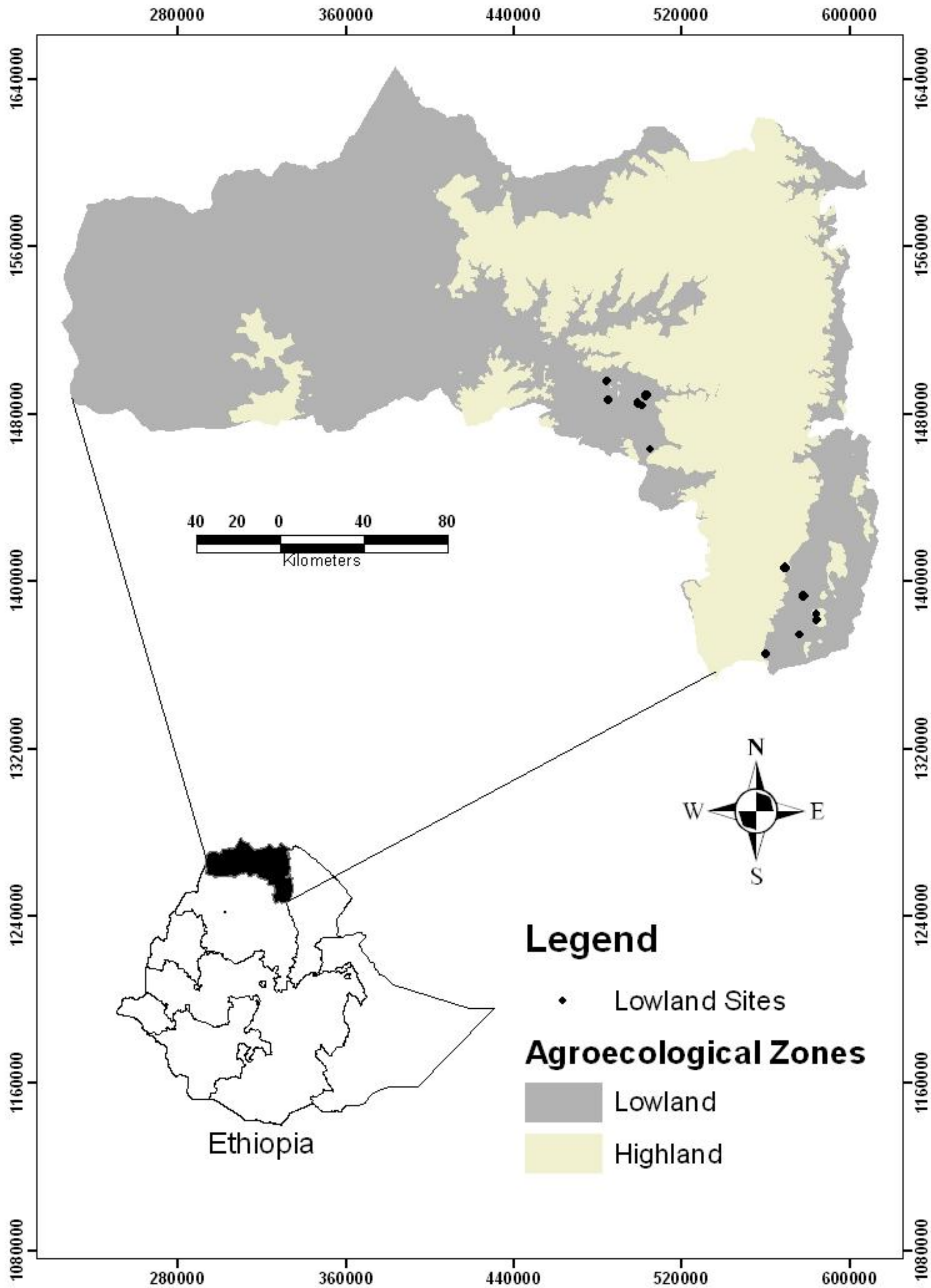

Figure 1. Location of the study area in the lowlands of Tigray (ranging from 500 to 1500 m a. s. l.), Northern Ethiopia with the distribution of specific sites indicated by (▪).

communal grazing lands. In total, we selected nine paired exclosures and grazing lands that are distributed throughout the lowlands of Tigray (Figure 1). The area of the selected exclosures ranged from 7.1 to 85 ha whereas that of the adjacent communal grazing lands ranged from 2.8 to 38.3 ha (Table 1). Natural features such as large gullies and man-made features such as roads usually

Table 1. Area, location and major soil types of exclosures and adjacent grazing lands.

Variable	Replicate	Site					
		5-Year exclosure	Adjacent grazing land	10-Year exclosure	Adjacent grazing land	15-Year exclosure	Adjacent grazing land
Area (ha)	I	18.2	5.5	28.9	38.3	19.7	14.0
	II	28.6	14.1	10.4	3.7	85.0	2.8
	III	7.1	11.2	14.5	12.4	10.8	3.7
District	I	Endamehoni		Endamehoni		Tanqua-Abergele	
	II	Alemata		Endamehoni		Tanqua-Abergele	
	III	Tanqua-Abergele		Tanqua-Abergele		Tanqua-Abergele	
Major soil type	I	Regosol	Regosol	Cambisol	Cambisol	Leptosol	Leptosol
	II	Regosol	Regosol	Regosol	Regosol	Leptosol	Leptosol
	III	Leptosol	Leptosol	Leptosol	Leptosol	Leptosol	Leptosol

demarcate the boundaries of exclosures and the adjacent grazing lands. Based on the fact that exclosures are not fenced, guards are hired by the local administration on a food-for-work basis (Yayneshet et al., 2009). In exclosures, grazing is not allowed, but grass harvesting (using a cut-and-carry system) is permitted once a year, typically after seeding stage, starting three to five years after exclosure establishment (Descheemaeker et al., 2006). The main reason to restrict grass harvesting is to restore the soil seed bank.

In the adjacent communal grazing lands, unlimited access for free grazing is practiced. Although, there is variation in managing the communal grazing lands across the lowlands of Tigray, the communal grazing lands are under heavy grazing pressure and severe land degradation as the communal grazing lands are grazed throughout the year and most of the people depend on fuel wood sourced from the communal grazing lands to meet their energy demand (Zenebe, 2007). In both exclosures and communal grazing lands, soil and water conservation structures such as hillside terraces, stone bunds, and micro-basins have been constructed. However, the soil and water conservation structures are in better conditions in exclosures (that is, not damaged by livestock or human) because livestock and human activities are restricted (Mekuria et al., 2011).

In addition to exclosures and the adjacent grazing lands, we selected three isolated forest fragments that remain around churches, also called “church forests”. In northern Ethiopia, the only areas where patches of forests can be found are areas surrounding the Ethiopian Orthodox Tewahido churches and these church forests have survived as a result of the traditional conservation system and protective patronage of the churches (Wassie et al., 2009). In the studied church forests, livestock grazing, collection of fuel wood and construction materials were allowed depending on the needs of the local community after thorough discussion among church administration and local communities on the need of specific use of forest resources. The area of the church forests in our study varied between 5.9 and 15.3 ha.

Experimental design

We used space-for-time substitution approach (Pickett, 1989; Fukami and Wardle, 2005) to detect changes in vegetation composition, diversity and aboveground biomass after conversion of communal grazing lands to exclosures with ages of 5, 10 and 15 years. This approach, which has a long tradition in ecology, is a method that is used to extrapolate temporal dynamics of vegetation succession by comparing multiple sites of different ages since disturbance or land use change in a region. In using space-for-time substitution approach, the experimenter does not establish the perturbation but instead selects sites where the perturbation is already running or has run.

The implicit assumption of this approach is that each paired communal grazing land and exclosure age should have comparable initial conditions such that changes in vegetation composition, diversity and aboveground biomass are a consequence of the land use change (that is, exclosure establishment). Thus, we selected sites with a pair of communal grazing land and exclosure adjacent to each other. Prior to establishment, exclosures and the adjacent communal grazing lands had similar conditions because the exclosures were established on part of the degraded communal grazing lands, which were used for livestock grazing (Mekuria et al., 2011). To cover the variability in soil and topography, we selected three replicates for each paired communal grazing land and exclosure age throughout the lowlands of Tigray (Figure 1). We also selected replicated (n = 3) church forests to detect whether exclosures had reached species richness and diversity level of these forests. At each exclosure, grazing land and church forest, we randomly established two to four transects spaced at a minimum distance of 75 m. The length of transects varied between 170 and 1340 m in exclosures, from 140 to 859 m in adjacent grazing lands and from 250 to 1120 m in church forests, depending on area of the site. The number of transects per site was based on vegetation density, spatial heterogeneity of vegetation, and area of the site (Mengistu et al., 2005). Transects were parallel to each other and to the topography of the landscape. Along each transect, we delineated three landscape positions (upper slope, mid slope and foot slope), and in each landscape position we established a sampling plot of 20 m × 20 m. In the entire study, we studied 153 sample plots of which 75 were in exclosures, 54 in adjacent communal grazing lands and 24 in church forests.

Vegetation inventory, analyses and estimation of aboveground standing biomass

In each 20 × 20 m plot, we measured the following individual plant variables: diameter at breast height (DBH), or for smaller and multi-stemmed shrub, diameter at stump height or at the height of 30 cm (d_{30}) from the ground, crown diameter and total height. DBH and d_{30} were measured using calipers. Crown diameter was measured using a measuring tape. Total height was measured using either a clinometer or a measuring tape depending on tree height. We also identified the species identity of plants encountered in each plot by the support of local people. For plants, which could not be identified in the field, herbarium specimens were collected, properly dried in a plant press, and identified at the National Herbarium in Addis Abeba University, where voucher specimens were deposited.

The average total density of woody plant species per hectare was derived from the total number of individuals recorded in the sample plots at each exclosure age (ranged from 24 to 27 plots, or 0.96 to 1.08 ha) and the respective adjacent communal grazing lands (18 plots, or 0.72 ha) as well as in the 24 plots (0.96 ha) at church forests. To determine the species similarities between exclosures, adjacent communal grazing lands and church forests, we used Sorensen's similarity index (Sorensen, 1948):

$$Ks = \frac{2c}{a+b} \times 100$$

Where, Ks = Sorensen's similarity coefficient; c = number of species common to both sites (that is, an exclosure age and the adjacent communal grazing land or an exclosure age and church forest); a, b = number of species found in site one and two (that is, in exclosure or in adjacent communal grazing land; in exclosure or church forest), respectively. To determine native (indigenous) plant species diversity in exclosures, adjacent communal grazing lands and church forests, and to conduct comparisons in species diversity between exclosures and adjacent communal grazing lands, we used the Shannon-Wiener index of diversity (*H*') (Shannon, 1948):

$$H' = -\sum_{i=1}^{s} P_i \ln(P_i),$$

Where, P_i is the proportion of individuals of the abundance of the ith species as expressed as a proportion of the total. We used only the Shannon-Wiener index of diversity because similar to Simpson's and other index it takes into account species richness and proportion of each species within a community (that is, within exclosures, adjacent communal grazing lands and church forests). To determine the similarity in abundance of different species within a community, we used the Shannon-Wiener index of evenness (J):

$$J = \frac{H'}{H'_{\max}} = -\sum_{i=1}^{s} P_i \ln\left(\frac{P_i}{\ln(s)}\right)$$

Furthermore, the type of plant species found in exclosures, adjacent communal grazing lands and church forests were described in terms of richness, plant family and life forms such as herbaceous-, shrub-, and tree-species. In our study, differences in species richness are equivalent to the value of beta diversity (that is, species turnover) provided that we did not encounter a species unique to the communal grazing lands.

To estimate aboveground biomass, we identified dominant woody species using our data on vegetation inventory. The dominant woody species were determined based on the relative importance value (that is, the sum of relative basal area, relative frequency and relative density) in each exclosure, adjacent communal grazing land and church forest. This approach ensures that species that are few in number but productive (that is, large biomass) are not excluded. The number of woody species selected for biomass estimation varied between 2 and 10 in exclosures, between 1 and 8 in adjacent communal grazing lands, and between three and 10 in church forests.

We used the methods of Hoff et al. (2002) and Snowdon et al. (2002) for measuring aboveground woody biomass. The dominant woody species were grouped into three diameter classes in order to minimize errors that can arise from variable sizes of individuals.

In exclosures and the adjacent communal grazing lands, we harvested and weighed selected individuals representing the dominant species. Altogether we harvested and weighed 270 trees and shrubs (162 from exclosures and 108 from communal grazing lands). In the church forests, the partial harvest method (Snowdon et al., 2002) was employed because tree felling is strictly forbidden; biomass was collected form 24 individuals. Fresh mass of aboveground vegetation was adjusted to dry mass using the measured moisture contents, determined by oven-drying sub samples of stems, branches, and leaves at 65°C until constant mass was attained (about 78 h).

Statistical analyses

We conducted paired t-tests to test for significant differences in density, plant species richness, diversity, evenness, and above-ground standing biomass of the naturally regenerated plant species between paired exclosures and adjacent communal grazing lands. We checked the equality of the variances in both groups before starting the interpretation of the statistical results from the t-tests. Pearson correlation tests were conducted to examine the relationships between plant species richness, diversity and above-ground biomass and independent variables using the mean values of the three landscape position for each land use type (n = 12).

RESULTS

Vegetation composition in exclosures and adjacent communal grazing lands

In exclosures, we recorded between 37 and 46 plant species representing 23 to 29 families, whereas we recorded between seven and 30 plant species representing six to 22 families in the adjacent communal grazing lands (Table 2). All exclosure ages contained equivalent number of plant families that were represented by two or more species. In all exclosures, Fabaceae/Leguminosae and Poaceae contributed the greatest number of species. Exclosures contained more herbaceous, shrub and tree species than the adjacent communal grazing lands (Table 3). Moreover, the number of shrub and tree species increased with the increase in exclosure age. However, the proportion of herbaceous and shrub species was considerable (ranging from 73% in the 5-year-old exclosure to 61% in the 15-year-old exclosure). The similarity of vegetation between an exclosure and the adjacent communal grazing land varied between 61 and 29 % and decreased with the increase in exclosure age (Figure 2).

Species richness, diversity and aboveground standing biomass in exclosures and adjacent communal grazing lands

All exclosures displayed higher plant species richness, diversity and aboveground standing biomass when compared to the adjacent communal grazing lands (Table 3). The 15 year-old exclosure displayed the highest proportional increase in species richness following establishment (that is, 80.4% increase compared to the adja-

Table 2. Total number of native plant species recorded in the entire sampled plots in exclosures, grazing lands and church forests*.

Variable	5-ex	AGL	10-ex	AGL	15-ex	AGL	Church forest
Total number of sampled plots	24	18	27	18	24	18	24
Area of the total sampled plots (ha)	0.96	0.72	1.08	0.72	0.96	0.72	0.96
Total number of species recorded	46	30	37	22	44	7	49
Plant families (number)	28	22	23	14	29	6	35
Families represented by two or more species (number)	7	4	7	4	6	1	8

*5-ex, 10-ex and 15-ex refer to 5, 10 and 15 years exclosures respectively. AGL, Adjacent grazing lands.

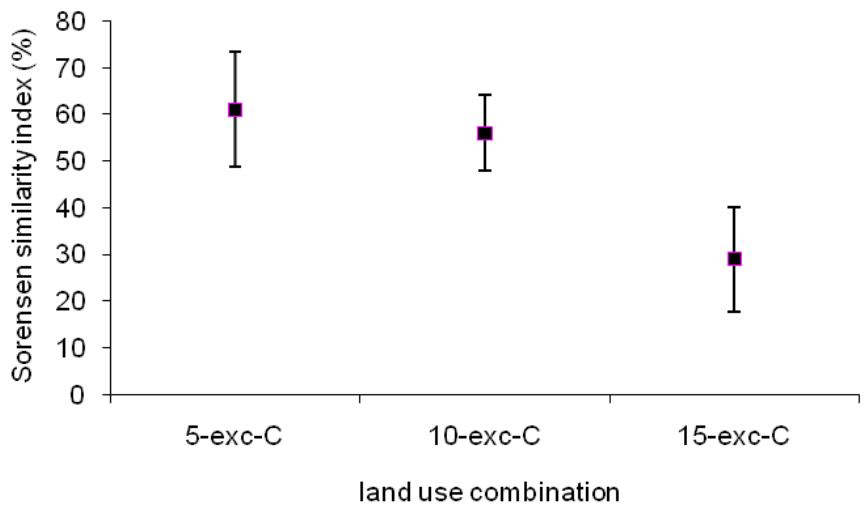

Figure 2. Sorenson similarities index (%) between an exclosure and adjacent communal grazing land. C refers to the adjacent communal grazing land for each respective exclosure age.

cent grazing land), while we observed the highest proportional increase in aboveground biomass in the 5 year-old exclosure (Table 3). The influence of exclosure age on plant species richness and diversity was not consistent, as the increases in plant species richness and diversity following the establishment of exclosures on communal grazing lands was significant ($p < 0.05$) only between 15-year-old exclosure and the adjacent communal grazing land (Table 3). However, the increase in aboveground biomass following the establishment of exclosures was significant ($p < 0.05$) between all paired exclosures and communal grazing lands (Table 3). Moreover, we did not detect significant differences ($p > 0.05$) in Shannon Wiener evenness index values between any of the exclosure ages and the adjacent communal grazing lands.

Relationships between soil properties and vegetation variables

In exclosures, plant species diversity, richness and aboveground standing biomass were positively and significantly ($p < 0.05$) correlated with % OM, % N, available P and clay content, while negatively correlated with sand and silt content (Table 4). In communal gra-zing lands, plant species diversity was positively and significantly ($p < 0.05$) correlated with % OM and silt content. Plant species richness was positively correlated with available P and sand content whereas negatively correlated with % OM and clay content. Aboveground biomass was positively correlated with % OM and clay content whereas negatively correlated with available P and sand content.

Vegetation variables in church forests

The total number of plant species recorded in the entire church forests was comparable with the total number of species recorded in exclosures (Table 2). Trees accounted for 33%, shrubs accounted for 31%, and herbaceous species, which includes grasses, climbers, forbs and epiphytes accounted for 36%. The average height of plant species found in the church forests was 4.2 (± 0.6) m, whereas the average total density was 954 (± 249) stem ha^{-1}. The Shannon-Wiener diversity value of plant species found in the church forests was 1.76.

Table 3. Average (± SE, n = 3) of plant species richness, diversity, evenness, aboveground standing biomass, vegetation cover, and herbaceous, shrub and tree species in exclosures and communal grazing lands and their differences.

Variable	Exclosure age (year)	Exclosure	Adjacent grazing land	Difference a	*t-value*
Richness (number)	5	19.6 (4.3)	12.0 (5.9)	7.6 (5.8)	1.05
	10	16.0 (2.1)	13.0 (5.2)	3.0 (3.2)	0.54
	15	24.0 (6.7)	4.7 (0.9)	19.3 (6.9)*	2.88
Diversity (Shannon Wiener index)	5	1.1 (0.6)	0.7 (0.5)	0.4 (0.22)	0.99
	10	1.3 (0.3)	1.0 (0.4)	0.3 (0.12)	1.04
	15	1.6 (0.3)	0.7 (0.3)	0.9 (0.25)**	3.71
Evenness (Shannon Wiener index)	5	0.48 (0.1)	0.3 (0.2)	0.18 (0.08)	1.28
	10	0.68 (0.09)	0.61 (0.16)	0.07 (0.09)	0.64
	15	0.64 (0.08)	0.59 (0.18)	0.05 (0.09)	0.49
Aboveground biomass (mg ha^{-1})	5	9.9 (1.20)	1.4 (0.4)	8.5 (0.6)**	17.7
	10	13.0 (2.9)	7.1 (2.5)	5.9 (0.9)*	2.65
	15	29.0 (8.4)	16.3 (7.3)	12.7 (1.5)**	7.31
Herbaceous species (number)	5	8.0 (0.6)	1.7 (1.2)	6.3 (1.7)**	4.75
	10	5.0 (0.5)	3.0 (0.6)	2.0 (0.6)	2.44
	15	7.0 (2.1)	0.3 (0.3)	6.7 (2.3)*	3.16
Shrub species (number)	5	6.3 (2.8)	6.7 (3.5)	-0.3 (3.8)	-0.07
	10	6.7 (0.9)	5.7 (2.6)	1.0 (1.7)	0.36
	15	7.7 (1.5)	1.3 (0.3)	6.3 (1.8)**	4.24
Tree species (number)	5	5.3 (1.2)	3.7 (1.3)	1.7 (0.3)	0.93
	10	4.3 (1.2)	4.3 (2.0)	0.0 (1.5)	0.00
	15	9.3 (3.2)	3.0 (0.6)	6.3 (2.9)	1.96
Total density (stem ha^{-1})	5	1260 (420)	699 (192)	561 (238)	1.21
	10	858 (102)	536 (55)	321 (46)*	2.76
	15	1203 (84)	428 (225)	775 (232)*	3.21
Height (m)	5	1.84 (0.13)	1.19 (0.44)	0.65 (0.53)	1.43
	10	2.48 (0.49)	2.31 (0.39)	0.17 (0.19)	0.28
	15	2.78 (0.41)	2.66 (0.53)	0.12 (0.26)	0.19
Canopy cover (%)	5	38.3 (5.1)	12.8 (3.2)	25.5 (7.3)**	9.26
	10	45.0 (6.8)	36.3 (5.5)	8.8 (6.1)*	3.39
	15	74.2 (5.4)	25.5 (7.6)	48.7 (9.0)**	13.2
Under-canopy cover (%)*	5	60.9 (4.7)	6.3 (0.7)	54.5 (4.7)**	10.9
	10	55.9 (6.1)	28.3 (4.4)	27.6 (5.5)**	7.91
	15	43.9 (6.8)	7.0 (3.6)	36.8 (8.2)**	35.7

*Under canopy cover refers mainly of grass cover. [a]Differences (calculated as: exclosure - adjacent grazing land) were significant at *$p \le 0.05$, **$p \le 0.01$ after paired t test.

DISCUSSION

Comparability of exclosures and the adjacent communal grazing lands

The inherent assumption of space-for-time substitution approach is that exclosures and the adjacent communal grazing lands had similar conditions before exclosure establishment. This assumption is confirmed by the fact that exclosures are established in the northern lowlands of Ethiopia on part of communal grazing lands that have been used for grazing in the past (Descheemaeker et al., 2006). In addition, we tested this assumption using varia-

Table 4. Pearson correlation coefficients (r; *n* = 12) between soil characteristics and plant species diversity, richness and aboveground standing biomass within exclosures and communal grazing lands.

Soil characteristic	Exclosure			Communal grazing land		
	Diversity	Richness	Biomass	Diversity	Richness	Biomass
% OM	0.44*	0.04	0.61*	0.49*	-0.62*	0.60*
% N	0.51*	0.23	0.70*	0.34	-0.19	0.09
P (ppm)	0.56*	0.06	0.53*	0.43	0.81*	-0.88*
% Sand	-0.62*	-0.30	-0.84*	-0.24	0.77*	-0.87*
% Silt	-0.12	-0.66*	-0.18	0.73*	-0.27	0.39
% Clay	0.64*	0.84*	0.88*	-0.39	-0.87*	0.90*

*Significant at $p < 0.05$.

bles measured in the paired exclosures and communal grazing lands that are less dependent on land use (e.g. soil texture) and detected no difference in soil texture between any of the paired exclosures and adjacent grazing lands (Mekuria et al., 2011). This indicates that the paired sites were comparable and differences in native plant species richness, diversity and aboveground standing biomass measured between the paired exclosures and adjacent communal grazing lands were mainly caused by land-use change (that is, exclosure establishment) and not by inherent site variability.

Aboveground biomass, plant species richness and diversity in communal grazing lands

In communal grazing lands, the low aboveground standing biomass, richness and diversity of plant species is a result of free grazing practices and human interference, resulting in severe overgrazing, which affects regeneration and growth of plant species negatively. A study in Ethiopia (Taddese et al., 2002) demonstrated that free grazing resulted in lower species richness and biomass when compared to ungrazed plots due to its impact on soil physical properties. Similarly, a study in Inner Mongolia, China also demonstrated that overgrazing resulted in severe damage to vegetation (Zhao et al., 2011). The degradation of plant species in the communal grazing lands that are included in our study is critical, as more than 90% of local communities depend on bio-energy sources (wood, dung) that are obtained from grazing lands to meet their household energy demand (Zenebe, 2007), illustrating the urgent need to restore these useful shrub and tree species.

Changes in aboveground biomass, species richness and diversity in relation to exclosure age

The higher plant species richness, diversity and aboveground standing biomass in all exclosures compared to the adjacent communal grazing lands (Table 3) illustrates that rehabilitation of the degraded grazing lands occurs in relatively short period of time after restricting human and livestock interference. Other case studies conducted in Ethiopia have also shown that exclosures provide favorable microhabitats for plants, which can be an effective method to improve aboveground biomass, density, composition and diversity of naturally regenerated plant species (Mengistu et al., 2005; Abebe et al., 2006; Yami et al., 2006; Berhane et al., 2007). Moreover, in semi-arid Kenya, Verdoodt et al. (2010) and Muchiru et al. (2009), in Iran, Hosseinzadeh et al. (2010), in semi-arid USA, Yeo (2005), in semi-arid Azerbaijan (Peper et al., 2010), and in southern Mongolian desert steppes (Wesche et al., 2010) demonstrated that woody and herbaceous species richness, diversity and aboveground biomass increased following the establishment of exclosures on communal grazing lands.

Plant species richness, diversity and aboveground biomass increased with exclosure age. This was supported: (1) by the decreasing trend of vegetation similarity between exclosures and grazing lands with the increase in exclosure age (Figure 2), and (2) by the increase in species turnover (or differences in species richness between exclosures and grazing lands, Table 3) with the increase in exclosure age. The strong increase in plant species richness during the first 5 years following exclosure establishment (Table 3) compared to the increase during the first 10 years following the establishment of exclosure on communal grazing lands is caused by the establishment of large numbers of herbaceous species resulting from the prohibition on harvesting grass and other herbaceous species. This result did support our expectation in which herbaceous species dominates in the younger exclosures and shrub and tree species in the older exclosures. A study in semi-arid Kenya (Oba et al., 2001) demonstrated that grazing exclosures may increase species richness to a certain level and the increase in species richness declines with age of exclosures indicating that long-term exclusion of grazing may not necessarily increase species richness in arid-zone grazing lands. The substantial increase in aboveground biomass and shrub and tree species with exclosure age could also explain the slower rate of the increase in plant species richness with exclosure age, as the increase in abundance of shrub and tree species and biomass reduce herbaceous and pioneer species richness. Similar results have been reported in other case studies in which plant species richness declines when biomass exceeds 500 g m^{-2} (Oba et al., 2001), and with the increase in abundance of shrub and tree species (e.g. Smit et al., 1999).

Yet, Angassa and Oba (2010) demonstrated that woody species richness, diversity and evenness were greater in younger exclosures than in the older exclosures in the southern Ethiopia rangelands. The difference could be attributed to the different environment, soils and type and management of the grazing lands. Osem et al. (2002, 2004) have also shown that exclosures may decrease plant diversity if the site is productive as productive sites promote higher plant growth and earlier canopy closure, which prevents further establishment of pioneer species. Anderson et al. (2007) demonstrated that excluding herbivores caused the strongest relative decreases in plant species richness where exclusion of herbivores increased available soil P. The increase in plant species richness and diversity in our exclosures may be due to the soil layer has been degraded and is therefore very unproductive (Mekuria et al., 2007, 2009). Our study illustrates that the level of degradation of communal grazing lands prior to the establishment of exclosures on communal grazing lands influences the effects of exclosures age in enhancing regenerated indigenous plant species richness and diversity.

The positive correlations in exclosures of % OM, % TN, % clay and available P with plant species richness, diversity and aboveground biomass show that soil fertility is important in enhancing the effectiveness of exclosures in restoring degraded indigenous vegetation in addition to rainfall and age of exclosures following exclosure establishment. This result is in consistent with our expectation in which we expected a higher plant species richness and diversity in relatively fertile sites as our sites are degraded. This was already suggested in an earlier study by Aerts et al. (2006), which indicated that the success of natural regeneration in exclosures will greatly depend on the quality of the physical environment and the proximity to forest remnants. Other studies conducted in other semi-arid ecosystems (e.g. Lane et al., 1998; Leger et al., 2007) have also shown that the positive influences of moisture and soil nutrient content on the number of woody species and aboveground net primary productivity. Similarly, the negative correlations of %sand and %silt with species richness, diversity and above-ground biomass illustrate the effect of poor soil fertility in reducing the effectiveness of exclosures to restore degraded native vegetations.

The total number of plant species recorded in the exclosures was comparable with the total number of species recorded in the church forests (Table 2), suggesting that in exclosures less than two decades was required to reach a level comparable to church forests. This was also evident from the relatively equivalent value of the Shannon-Wiener diversity index of the 15-year old exclosures (H= 1.6) compared with the church forests (H= 1.76). Quite a lot of species were unique to exclosures and church forests (that is, high beta-diversity) although the majority of these species are herbaceous and small shrub species. Compared with natural dry afromontane forests in Ethiopia, all exclosures had a lower number of woody species (e.g. Alelign et al., 2007). Also, the Shannon-Wiener diversity index of all exclosures (H ranging from 1.1 to 1.6) was much lower compared to dry afromontane forest (H ranging from 2.72 to 3.72) (Woldemariam et al., 2000; Alelign et al., 2007). This illustrates that even the 15-year-old exclosures are in a relatively early successional stage. Compared to native forests, church forests are very small forest fragments containing a species-poor tree and shrub communities. They are, however, important for their role in the landscape ecology of the area as species pools (Aerts et al., 2006). As their area increases, with time, exclosures may increasingly obtain a similar role to church forests and should be protected and managed accordingly.

Conclusions

The results of this study confirm that the establishment of exclosures on degraded communal grazing lands in the northern lowlands of Ethiopia is a viable option to restore native vegetation composition, richness, diversity and aboveground biomass. Our study showed that soil fertility and level of degradation of communal grazing lands prior to exclosure establishment moderates the effectiveness of exclosures in improving vegetation composition and diversity and enhancing aboveground biomass. Such information is necessary to optimize the selection of areas for the establishment of exclosures in the future and for policymakers to take into account the importance of level of degradation of communal grazing lands in their management decisions. Moreover, our study suggests that with time exclosures in the northern lowlands of Ethiopia may increasingly obtain an important role as source of seeds of indigenous plant species and species pool similar to church forests and should be protected and managed. We do believe that the regional and district level agricultural offices should work to expand exclosure land management in order to restore degraded communal grazing lands and maximize benefits from these degraded resources. Community participation in selecting areas for exclosure establishment should also continue to ensure the sustainability of exclosure land management. However, care should be taken in identifying the availability of land for livestock grazing while expanding exclosures because expansion of exclosures could increase grazing pressure on the remaining communal grazing lands and aggravate land degradation.

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