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Restoration of degraded landscapes for ecosystem services in North-Western Ethiopia

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Abstract

Establishing exclosures has become common in Ethiopia, especially in the central and northern highlands, where they serve as a response to persistent forest degradation, affecting forest resources and ecosystem services. We investigated changes in vegetation composition, aboveground biomass and soil properties after establishing an exclosure on degraded communal grazing land in Aba-Gerima watershed, North-Western Ethiopia. We selected 4-yr-old exclosure and paired the selected exclosure with an adjacent communal grazing land. In the exclosure, we recorded 46 plant species representing 32 families, whereas we recorded 18 plant species representing 13 families in the adjacent communal grazing lands. Most of the identified woody species are economically important. We observed significant differences between the exclosure and adjacent grazing land in woody species richness, diversity and evenness. Exclosure displayed higher woody species density, basal area and aboveground woody biomass compared to the adjacent grazing land. Landscape position influenced vegetation composition, richness and diversity in the exclosure and adjacent grazing land. Significant differences between the exclosure and adjacent grazing land in soil properties were detected. The influence of landscape positions on soil properties was not

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consistent. At foot slope position, in the 0- to 15-cm and 15- to 30-cm depths, soil organic carbon and nitrogen content detected in exclosure were significantly higher when compared to the values observed in the adjacent grazing land. However, differences at mid and upper slope positions were not significant. The results support that the establishment of exclosures on degraded lands could support the restoration of degraded native vegetation and soil properties, which consequently enhance the ecosystem services that can be obtained from degraded lands.

Keywords: Environmental science, Geography

1. Introduction

Land degradation, which is defined as the long-term loss of ecosystems services, is a major global problem (Nkonya et al., 2016). Land degradation hotpots cover about 29% of global land area and are affecting about 3.2 billion people (Le et al., 2016). Land degradation takes many forms and affects forests, soils, water, biodiversity and economics and social services derived from the ecosystem (Nachtergaele and Petri, 2008). Land degradation is occurring in almost all terrestrial biomes and agro-ecologies, in both low and high-income countries (Nkonya et al., 2016). However, the impact is especially severe on the livelihoods of the poor who heavily depend on natural resources (Lal, 1995; Nellemann et al., 2009; Obalum et al., 2012; UNCCD, 2013; Jones et al., 2013; MacDicken et al., 2016). Sub-Saharan Africa (SSA) has experienced the most severe land degradation in the world, and accounts for the largest share at 22 percent of the total global cost of land degradation (Nkonya et al., 2016).

Like other SSA countries, land resources in Ethiopia are facing intense degradation due to proximate drivers such as deforestation, soil erosion, agricultural land expansion and overgrazing (Tekle, 1999; Paulos, 2001; Nyssen et al., 2004), as well as other underlying drivers, such as weak regulatory context and institutions, demographic growth, unclear user rights to land, low empowerment of local communities, and poverty generally (Kirui and Mirzabaev, 2014). Recent estimates put the size of degraded land at over one-quarter of the entire country, which affects nearly a third of the population (Chirwa, 2014; Gebreselassie et al., 2016). Land degradation is particularly severe in the north and north-western regions of the Ethiopia, as in these areas, steep slopes have been cultivated for many centuries and are subject to serious soil erosion (Mekuria et al., 2007, 2009, 2011a,b). For example, about 2.6 million hectares of the Amhara National Regional State (i.e., where this research is conducted) is considered as degraded with about 200,000−300,000 hectares of land covered by gullies (Lakew and Belayneh, 2012). About 70% of the region experiences moderate ($>$15 tons ha^{-1} yr^{-1}) to very high erosion rates ($>$30 tons ha^{-1} yr^{-1}); the regional forest resource has diminished (Meseret, 2016).

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Restoring degraded lands can be an effective solution for improving vegetation composition, sequestering carbon in vegetation and soil, and improving hydrological cycles and micro-climate (Mekuria et al., 2011b; Chirwa, 2014; Bortoleto et al., 2016; Dagnew et al., 2017). Various studies have demonstrated that landscape restoration not only delivers all these benefits, but against costs that are easily outweighed by the benefits (De Groot et al., 2013; UNEP, 2015). Notably, the government of Ethiopia launched nationwide ecological restoration programs in 2010 to restore degraded ecosystems and mitigate human pressures on natural ecosystems, toward improving the ecosystem services they provide, reversing biodiversity losses and increasing agricultural productivity (MOFED, 2010).

The ecological restoration program mainly focused on the construction of soil and water conservation (SWC) structures such as terraces and bunds on the hillslope and cultivated lands, gully treatments and stabilization, as well as establishing exclosures on communal grazing lands. During the period 2010–2015, for example, more than 15 million people have contributed unpaid labour equivalent of US$ 750 million each year (Seyoum, 2016). Benin et al. (2010) also show that Ethiopia is one of the six African countries that reached the Maputo Declaration target of spending 10% or more of the annual government budget on agriculture and Sustainable Land Management (SLM). During this same period (i.e., 2010–2015), SWC measures have been introduced in more than 3000 watersheds and more than 12 million hectares of land have been rehabilitated through implementing physical and biological conservation measures, including exclosures (Lemenih and Kassa, 2014; Seyoum, 2016).

Exclosures are common land areas, which are traditionally ‘open access,’ where wood cutting, grazing, and other agricultural activities are forbidden or strictly limited as a means to promote the restoration and natural regeneration of degraded lands (Tesfaye et al., 2015). Restoring degraded ecosystems through the establishment of exclosures has become a common practice in the Ethiopian highlands (Mekuria et al., 2017). Also, the use of exclosures has gained widespread acceptance as a means to restore degraded rangeland ecosystems in many of the world’s semi-arid rangelands (Verdoodt et al., 2009). For example, Young-Zhong et al. (2005) have shown that excluding grazing livestock is considered as an alternative to restore vegetation in the semiarid Horqin sandy grassland of northern China. Rehabilitation of degraded rangelands has also been fostered through establishment of exclosures in Tanzania (Barrow and Shah, 2011), Kenya (Wilkerson et al., 2013; Mureithi et al., 2014), South Africa (Siebert et al., 2010), and Pakistan (Qasim et al., 2017).

The existing wider implementation of exclosures in the highlands of Ethiopia is related to the multifaceted benefits of exclosures. The many benefits of exclosure include increasing vegetation cover and biodiversity (Asefa et al., 2003; Mengistu et al., 2005; Mekuria and Veldkamp, 2012), enhancing ecosystem carbon stocks

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(Mekuria et al. 2011b, 2015; Aynekulu et al., 2017), reducing soil erosion (Mekuria et al., 2009), restoring soil fertility (Descheemaeker et al., 2009; Damene et al., 2013; Mekuria and Aynekulu, 2013; Mekuria et al., 2017), increasing in dry season flow (or water availability in the dry season) (Dessalew et al., 2016), decreasing runoff and sediment load (Descheemaeker et al., 2006; Girmay et al., 2009; Anwar et al., 2016), increasing in groundwater recharge (Anwar et al., 2016), and increasing in incomes and improving livelihood of smallholder farmers by providing opportunities to diversify livelihood (Tilahun et al., 2007; Babulo et al., 2009; Mekuria et al., 2011a). The expansion of area under exclosures could therefore contribute to improved livelihoods over the medium- to long-term.

Although there are encouraging results, the magnitude of the current scale of land degradation underscores the need for evidence-based restoration (Abiyu et al., 2017), as the drivers and costs of land degradation, as well as the effectiveness of exclosures to restore degraded landscapes, differ across localities due to the heterogeneity of local communities and management approaches (Mekuria et al., 2017). Also, existing case studies cannot adequately represent the diversity in soil, slope, exclosure management, climate, and topography in the Ethiopian highlands (Mekuria et al., 2015). Further, studies have shown that the impacts of exclosures on soil properties were site dependent (Potter et al., 2001; Reeder et al., 2004; Young-Zhong et al., 2005).

To restore degraded communal grazing land, an exclosure was established in Aba-Gerima watershed, located in North-Western Ethiopia in 2012 (WLRC, 2012). This study was conducted in the region to investigate changes in vegetation composition, aboveground woody biomass and soil properties after the establishment of the exclosure on degraded communal grazing land. The key research questions that this paper addressed is that how do exclosures influence the restoration of native vegetation, enhancement of aboveground biomass and improvement of soil properties.

2. Material and methods

2.1. Study area

The study was conducted in Aba-Gerima watershed[1], located in Bahir-Dar Zuriya Wereda, west Gojam administrative zone of Amhara region in North-Western Ethiopia (Fig. 1). It covers an area of 900 ha, and has a total beneficiary population of 446 households (WLRC, 2012). Agriculture is the predominant sector of the economy in the Aba-Gerima watershed. However, there is an increasing conversion of croplands into Khat cultivation. The agricultural sector is primarily dependent on

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[1] The watershed is located at (39^0 29′ 57″ E longitude and 11^0 39′ 59″ N latitude).

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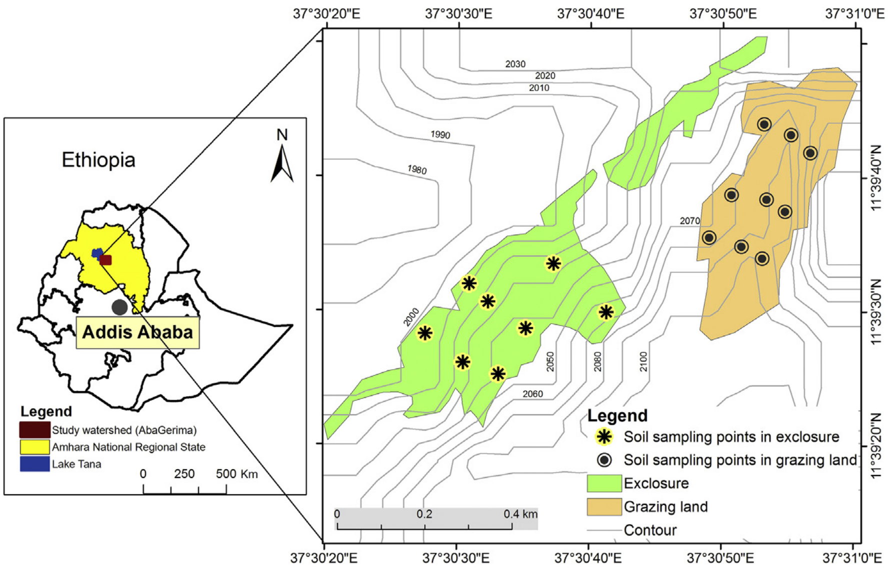

Fig. 1. Location of the study area and studied watershed.

smallholder farming. According to WLRC (2012), the average crop yields of major cultivated crops were about 1.3 ton ha^{-1}for teff, 3.5 ton ha^{-1} for maize, 2.2 ton ha^{-1} for millet, and 2.8 ton ha^{-1} for barley.

Natural resources degradation is one of the socio-economic and environmental challenges of the Aba-Gerima watershed (WLRC, 2012). The degradation of natural resources has resulted in (a) poor soil fertility, (b) severe soil erosion by water, especially at mid and upper slope positions, (c) depletion of vegetation cover and indigenous trees, and (d) reduced access to surface and groundwater as well as poor water quality. This in turn resulted in reduced crop productivity and local community resilience to climate change and variability.

In response to natural resource degradation problems, the Water and Land Resource Centre (WLRC) in collaboration with the Amhara Regional Agricultural Research Institute (ARARI), Bureau of Agriculture (BoA) and the local community started land rehabilitation efforts through the implementation of SLM practices including exclosure establishment and the construction of SWC structures since 2012 (Adgo and Zeleke, 2015). After four years since the start of the implementation of SLM practices (i.e., in 2015), about 760 ha of the watershed were covered with different SWC measures including soil and stone bunds, fanya juu terraces[2], cut-off drain, waterways and exclosures (Adgo and Zeleke, 2015).

The ecological succession through the establishment of exclosures in Aba-Gerima watershed was managed by the assisted strategy technique. Accordingly, planting

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[2] Fanya juu (‘throw it upwards’ in Kiswahili) terraces comprise embankments (bunds), which are constructed by digging ditches and heaping the soil on the upper sides to form the bunds.

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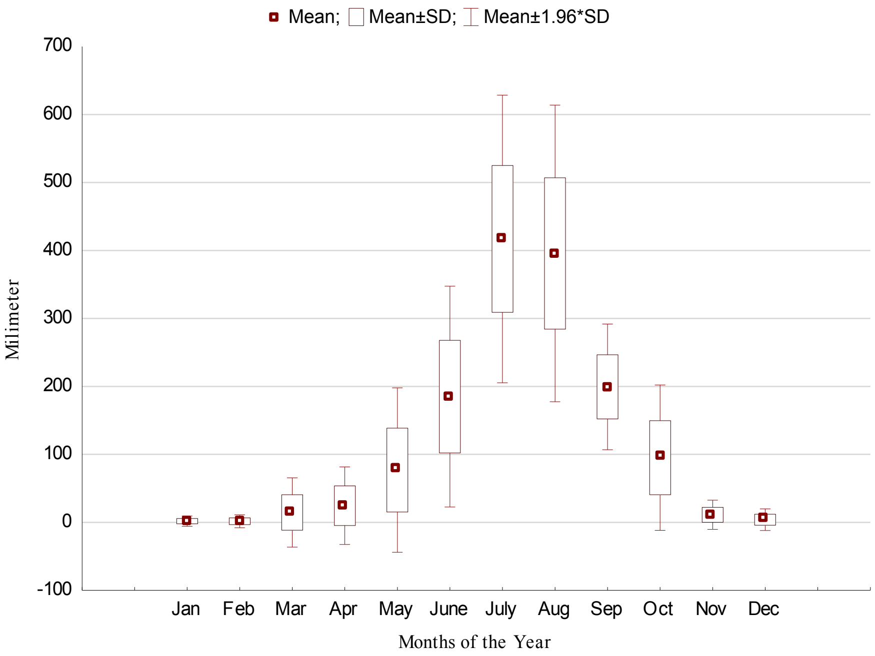

Fig. 2. Mean monthly rainfall in the study site (time span 1996–2015).

of both exotic and indigenous seedlings[3], aerial seeding of tree and grasses, and construction of soil and water conservation structures[4] were conducted after the establishment of exclosures. The main reason for managing using such technique is to speed up succession through the modification of microclimatic and soil conditions. In exclosures, grass harvesting for fodder using a 'cut and carry' system, honey production and collection of medicinal plants are allowed. Grass is harvested once a year, usually after the seeding stage, starting 2–3 years after exclosure establishment. The main reason to restrict grass harvesting is to restore the soil seed bank.

According to WLRC (2012), Aba-Gerima watershed has a woina dega sub-tropical continental climate. Based on 20-years (1996–2015) data obtained from Bahir-Dar meteorological station (15 km far from the study site), the mean annual rainfall varied between 1163 and 1685 mm with a mean value of 1428 (±35) mm yr^{-1} (Fig. 2). The rainy season usually occurs between June and September in which 84% of annual rainfall occurs (Fig. 2). The mean annual minimum and maximum temperature is 12.6 and 27.4 °C, respectively. The mean monthly minimum temperature varied between 8.5 and 15.4 °C, while the mean monthly maximum temperature ranges from 24.6 to 30.4 °C (Fig. 3). The elevation of the watershed ranges from 1893 to 2120 meter above sea level (WLRC, 2012).

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[3] Exotic plant species such as *Sesbania sesban*, *Cajanus cajan* and *Grevillea robusta*, and indigenous species including *Cordia Africana* and *Olea species* were planted following establishing exclosures.
[4] Soil and water conservation structures implemented within exclosures include hillside terraces, stone bunds and micro-basins.

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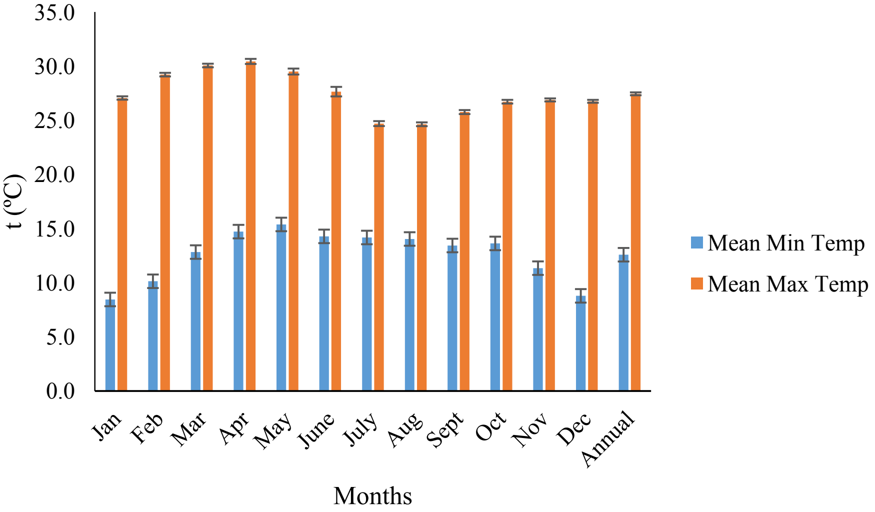

Fig. 3. Mean monthly and annual minimum and maximum temperature (time span 1996–2015). Bars in the figure indicate standard errors of means.

Major land uses in the watershed include cultivated lands (66% of the area), plantation forest (2.3 %), bushes and shrubs (4.3 %), and open grassland (20.7 %). Soils of the watershed were classified into two major groups: Nitosols and Leptosols (WRB, 2015; Nigussie et al., 2017). Indigenous woody vegetation species in the watershed include *Carissa spinarum* (L.), *Bersama abyssinica* (Fressen), *Croton macrostachyus* (Del.), *Senna singueana* (Del.) *Lock, Osyris quadripartite, Dodonaea angustifolia* (L.f.), *Calpurnia aurea* (Alt.) Benth and *Vernonia auriculifera Hiern*. Grass species dominate the understory vegetation of the exclosure and communal grazing land.

We selected a 4-year old exclosure and an adjacent communal grazing land as a control treatment (Fig. 1). We assumed that, before establishment, the exclosure and the communal grazing land were in similar condition because the exclosure was established on the same communal grazing lands that were used for livestock grazing. The area of the exclosure was 17 ha, while the communal grazing land covers an area of 13 ha.

2.2. Experimental design

We followed the method of Mekuria et al. (2011b), and selected a paired exclosure and adjacent grazing land to assess the effectiveness of exclosures to restoring vegetation composition, aboveground woody biomass and soil properties. The key differences between the present and the previous study include climate, site variables (e.g., soil, vegetation type) and management. The use of similar method enables us to compare data with similar studies, and assess the effectiveness of exclosures under different ecological and management conditions. The selection of

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paired grazing land and exclosure enables us to understand how land use change influences vegetation composition and soil properties. In the exclosure and adjacent grazing land, we randomly established three transects spaced at a minimum distance of 200 m. The first transect was laid 30−50 m inside the exclosure or grazing land. In 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 10 by 10 m. The inclusion of landscape position in our sampling design supports to characterize the effects of topography-related processes on vegetation composition and soil properties. The upper slope position contributes runoff to mid- and foot-slope positions. Among the three landscape positions, the foot slope receives the higher overland flow and depositions (Mekuria et al., 2009). Soil, vegetation, and management-related data were collected from May to December 2015.

2.3. Vegetation inventory and analyses

In each 10 m × 10 m plot, we measured vegetation variables including diameter at breast height (DBH), or for smaller and multi-stemmed shrub, diameter at stump height or at a height of 30 cm (d_{30}) from the ground, crown diameter and total height. Calipers and a measuring tape were used to measure diameter and crown diameter and height, respectively. We also identified the species of plants encountered in each plot. In the exclosure and adjacent grazing land, we studied 18 sample plots (i.e., 9 in exclosure and 9 in adjacent grazing land) (Fig. 1).

The average total density of plant species per hectare was derived from the total number of individuals recorded in the sample plots in the exclosure and adjacent grazing land. We used standard methods to compare species similarities, diversity and evenness between exclosure and grazing land as well as between the landscape positions in exclosure and grazing land (Table 1). The types of plant species found in exclosure and adjacent communal grazing land were described in terms of richness, plant family and life form, such as herbaceous, shrub and tree species. Literature review and key informant interviews were used to assess the local uses of the identified plant species.

2.4. Estimation of aboveground woody biomass

To estimate above-ground biomass, we identified dominant woody species using our inventory data. The dominant woody species in the exclosure and adjacent grazing land were determined based on the relative importance value (i.e. the sum of relative basal area, relative frequency and relative density). This approach ensures that species that are few in number but productive are not excluded. The number of woody species selected for biomass estimation were 8 at the exclosures and 4 at the adjacent grazing land.

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Table 1. Methods and equations used for the analyses of vegetation and soil variable as well as for statistical analyses.

(a) Vegetation inventory and analyses and aboveground biomass estimation

Vegetation variables	Method used	Equations	References
Species similarities	Sorensen's similarity index	$Ks = \frac{2c}{a + b} \times 100$	Sorensen (1948)
Species diversity	Shannon-Wiener index of diversity	$H' = \sum_{i=1}^{s} p_i \ln(p_i)$	Shannon (1948).
Similarities in species abundance	Shannon-Wiener index of evenness (J).	$J = \frac{H''}{{\prime}H'_{\max}}{\prime} = -\sum_{i=1}^{s} P_i \ln\left(\frac{P_i}{\ln (s)}\right)$	Shannon (1948).
Plot level density (No. ha^{-1})		$D_p = \frac{10^4 \times n}{Plot\ size\ (m^2)}$	
Site (total) density (No. ha^{-1})		$D_t = \frac{10^4 \times N}{Total\ plot\ size\ (m^2)}$	
Aboveground biomass	Destructive sampling		Hoff et al. (2002); Snowdon et al. (2002).

(b) Soil laboratory analyses

Soil properties	Method used	Reference
Soil organic C	Walkley−Black method	Walkley and Black (1934),
Soil nitrogen	Kjeldahl method	Bremmer and Mulvaney (1982)
Available Phosphorous	Olsen method	Olsen et al. (1982)
CEC	Ammonium acetate method	Thomas (1982)
Bulk density	Core method	Blake and Hartge (1986)
Particle size	Hydrometer method	Gee and Bauder (1986)
Soil pH	1:2.5 soil water suspension	

c) Statistical analyses

Comparisons	Variables	Statistical test
Differences between exclosures and adjacent grazing land	Vegetation variables and soil properties	Paired t-test
Differences between landscape positions in exclosure and grazing land	Vegetation variables and soil properties	ANOVA

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We used destructive sampling to estimate aboveground woody biomass (Table 1). The dominant woody species were grouped into three diameter classes in order to minimize errors that can arise from variable sizes of individuals. The selected individuals representing the dominant species were harvested and weighted. Altogether we harvested 36 trees and shrubs (24 from the exclosure and 12 from the adjacent grazing land). Fresh mass of aboveground vegetation was adjusted to dry mass using the measured moisture content, determined by oven drying sub-samples of stems, branches and leaves at 65 °C until constant mass was attained (about 78 h).

2.5. Soil sampling and laboratory analyses

In each 10 m × 10 m plot, we collected soil samples at the 0- to 15 and 15- to 30-cm depths. In each plot, we collected soil samples at four sampling points. We chose to sample at these two depths to consider the effects of plant roots in soil properties, as most of the exclosures are dominated by indigenous shrub and tree species. One soil core sample (having a size of 100 cm^3) from both depths was also taken from each plot for bulk density determination. The samples collected from each plot (i.e. four sampling points) were mixed thoroughly in a large bucket to form one composite soil sample per plot. During the entire study, we collected a total of 36 composite soil samples (i.e. [2 (sites) × 9 (plots per site) × 2 (sampling depths)] = 36). The soil samples were air dried, ground and sieved through a 2-mm sieve before analysis. The methods used to determine the soil variables in the laboratory are summarized in Table 1.

2.6. Data analyses

The differences between the exclosure and adjacent grazing land in vegetation richness, diversity, density and aboveground biomass as well as in soil properties were assessed using a paired t-test. The differences between landscape positions in the exclosure and adjacent grazing land were also assessed using one-way analyses of variance. We used STATISTICA 10·0 Software (Tulsa, OK, USA) to perform statistical analyses.

3. Results

3.1. Vegetation composition in exclosure and grazing land

In the exclosure, we recorded 46 plant species representing 32 families, whereas we recorded 18 plant species representing 13 families in the adjacent communal grazing land (Table 2). We identified more plant families that were represented by two or more species in the exclosure than the adjacent grazing land. In both exclosure and adjacent grazing land, Fabaceae contributed the greatest number of species. The exclosure contained more shrub, shrub/tree and tree species than the adjacent

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Table 2. Total number of plant species recorded in the entire sampled plots in exclosure and adjacent grazing land.

Variables	Exclosure	Adjacent grazing land
Total number of sampled plots	9	9
Area of total sampled plots (ha)	0.15	0.09
Total number of species recorded	46	18
Plant families (number)	32	13
Families represented by two or more species (number)	5	2
Climbing plants (%)*	4.9	18.8
Shrub (%)	39.0	31.2
Shrub/tree (%)	29.3	25.0
Tree (%)	26.8	25.0

* Climbing plants are plants which climb up trees and other tall objects.

communal grazing land (Table 2). The proportion of shrub and shrub/tree species was considerable in both the exclosure and adjacent grazing land. The similarity of vegetation between the exclosure and the adjacent communal grazing land was 34.3 % (Table 3).

Most of the species identified in the exclosure (89% of the identified woody species) and adjacent grazing land (83%) are economically important. For example, the local people use the identified woody species for several purposes (Fig. 4). Uses described as others in Fig. 4 refer to uses such as household tool making, ornamental plant, washing of cloths, washing of traditional jewelleries, alcohol making, non-timber forest products such as gums and resins, termite protection, smoothening of leather, washing of household utensils, tooth brushing, and fumigation of traditional utensils.

Table 3. The similarity of vegetation between the exclosure and adjacent grazing land, and within the landscape positions in the exclosure and adjacent grazing land.

	Similarity in Vegetation (%)						
	Exclosure			Grazing land			Exclosure and Grazing land
	Upper	Mid	Foot	Upper	Mid	Foot	
Upper slope		57	44		74	56	54
Mid Slope	57		73	74		78	46
Foot Slope	44	73		56	78		33
Exclosure and grazing land							34.3

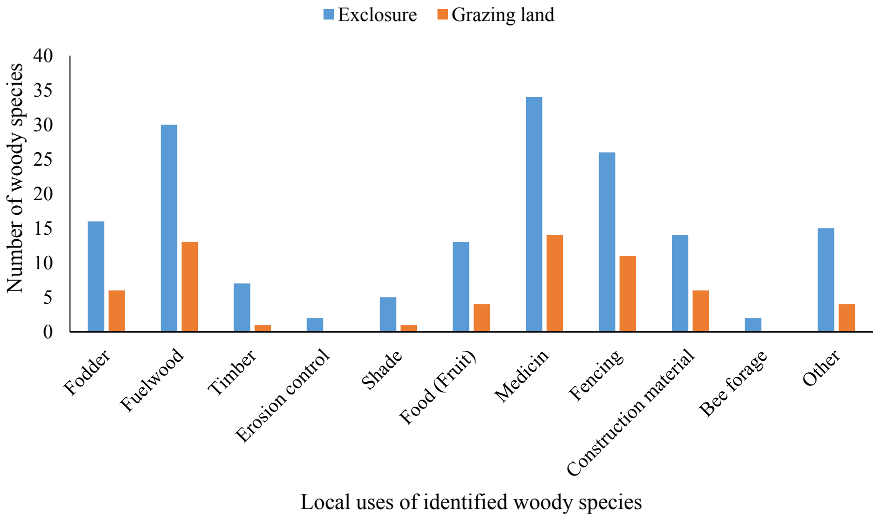

Fig. 4. Local uses of the species identified in exclosure and adjacent grazing land.

3.2. Vegetation variables in exclosure and adjacent grazing land

After 4 years of the establishment, the exclosure displayed higher plant species richness and diversity compared to the adjacent grazing land (Table 4). Plot level species richness in the exclosure varied between 7 and 26, whereas the plot level species richness ranged from 4 to 15 in the adjacent grazing land (Table 4). Differences between the exclosure and adjacent grazing land in woody species richness, diversity and evenness were highly significant ($p < 0.01$). Moreover, the exclosure displayed higher woody species density, basal area and aboveground woody biomass compared to the adjacent grazing land (Table 4). Plot level woody species density in the exclosure and adjacent grazing land varied between 1600 and 9100 individuals ha^{-1}, and 700 and 7500 individuals ha^{-1}, respectively (Table 4). Plot level basal area in exclosure varied between 1.25 and 11.2 m^2 ha^{-1}, whereas the plot level basal area ranged from 1.95 to 6.42 m^2 ha^{-1}in the adjacent grazing land (Table 4). Further,

Table 4. Mean (±standard errors) species richness, diversity, evenness, density (No ha^{-1}), basal area (m^2 ha^{-1}) and aboveground biomass (t ha^{-1}) in the exclosure and adjacent grazing land.

Variable	Mean (Exclosure)	Mean (Grazing)	t-value	Min - Max (Exclosure)	Min − Max (Grazing)
Richness	16.11 (±2.2)	7.78 (±1.2)	3.30**	7.0−26.0	4.0−15.0
Diversity	2.23 (±0.14)	1.37 (±0.1)	4.87**	1.55−2.86	1.02−1.90
Evenness	0.83 (±0.03)	0.70 (±0.02)	3.14**	0.70−096	0.53−0.75
Density	4705 (±994)	4544 (±853)	0.12	1600−9100	700−7500
Basal area	5.6 (±1.22)	3.8 (±0.43)	1.37	1.25−11.2	1.95−6.42
Biomass	14.82 (5.8)	9.93 (3.6)	0.72	7.2−26.3	4.2−16.5

**Significant at $p < 0.01$.

though it was not significant, considerable (49%) difference between the exclosure and adjacent grazing land in aboveground woody biomass was detected (Table 4).

3.3. Vegetation variables as influenced by landscape positions

The highest similarity in vegetation between the exclosure and adjacent grazing land was observed in the upper slope position (Table 3). In the exclosure, the similarity of vegetation between the three landscape positions varied between 44 and 73%, whereas it ranged from 56 to 78 in the adjacent grazing land (Table 3).

At each landscape position, the exclosure displayed higher plant species richness, diversity and basal area compared to the adjacent grazing land (Table 5). Moreover, significant ($p < 0.05$) differences were observed at upper- and foot-slope positions (Table 5). In the exclosure, higher species richness, diversity, density and basal area were observed at foot slope position compared to the mid- and upper-slope positions. However, the higher species richness, diversity and basal area were observed at upper slope position compared to the mid- and foot-slope positions in the adjacent grazing land. Significant differences in species richness and diversity among landscape positions within the exclosure and adjacent grazing land were not detected ($p > 0.05$). However, significant ($p < 0.05$) differences in woody species density and basal area among landscape positions within the exclosure were detected (Table 5).

3.4. Soil properties in the exclosure and adjacent grazing land

In the 0- to 15-cm depth, the exclosure displayed significantly ($p < 0.05$) higher cation exchange capacity (CEC) than the adjacent grazing land (Table 6). Also,

Table 5. Vegetation variables among landscape positions within the exclosure and adjacent grazing land. Values in the brackets are standard errors.

Landscape positions	Vegetation variables	Mean (±SE, n = 3)		t-value	Min - Max	Min-Max
		Exclosure	Grazing		Exclosure	Grazing
Upper slope	Richness	11.67 (±0.66)	11.33 (±1.85)	0.17	11.0−13.0	9.0−15
	Diversity	2.16 (±0.13)	1.55 (±0.21)	2.41	1.90−2.31	1.16−1.90
	Evenness	0.88 (±0.07)	0.64 (±0.06)	2.69*	0.74−0.96	0.53−0.70
	Density	2100 (360)^a	4800 (2084)	−1.27	1600−2800	700−7500
	Basal area	2.30 (0.57)^a	4.04 (0.30)	−2.69*	1.25−3.22	3.48−4.52
Mid slope	Richness	14.67 (±4.97)	6.33 (±1.20)	1.63	7.0−24.0	4.0−8.0
	Diversity	1.87 (0.21)	1.32 (0.16)	2.05	1.55−2.28	1.02−1.56
	Evenness	0.73 (±0.03)	0.73 (±0.01)	0.00	0.70−0.79	0.71−0.75
	Density	3483 (289)^b	5733 (868)	−2.45	3100−4050	4000−6700
	Basal area	4.5 (0.65)^a	3.5 (0.53)	1.18	3.17−5.22	2.60−4.42
Foot slope	Richness	22.00 (±2.64)	5.67 (±1.20)	5.62*	17.0−26.0	4.0−8.0
	Diversity	2.65 (±0.18)	1.23 (±0.15)	5.99*	2.29−2.86	1.02−1.53
	Evenness	0.88 (±0.04)	0.73 (±0.01)	3.60*	0.81−0.95	0.71−0.74
	Density	8533 (425)^c	3100 (1365)	3.79*	7700−9100	900−5600
	Basal area	10.0 (1.14)^b	3.96 (1.31)	3.49*	7.74−11.19	1.95−6.42

Note: different letter in the same column indicate significant differences among landscape positions at $p < 0.05$. * refers significant difference between exclosure and adjacent grazing land at $p < 0.05$.

Table 6. Soil properties in the 0- to 15 and 15- to 30- cm depths in exclosure and adjacent grazing land.

Landscape positions	**Soil properties**	**0- to 15-cm**			**15- to 30-cm**		
		Mean (±SE, n ≥ 3)		***t-value***	**Mean (±SE, n ≥ 3)**		***t-value***
		Exclosure	**Grazing**		**Exclosure**	**Grazing**	
Upper slope	pH	6.2 (±0.1)	6.5 (±0.1)	−2.4*	6.2 (±0.1)	6.5 (±0.1)	−2.6*
	OC (%)	2.5 (±0.2)	3.3 (±0.5)	−1.5	2.3 (±0.4)	1.7 (±0.2)	1.4
	Available P (ppm)	7.7 (±3.7)	6.4 (±2.1)	0.3	1.8 (±0.3)	3.3 (±0.2)	−4.0*
	Total N (%)	0.2 (±0.0)	0.3 (±0.0)	−1.2	0.2 (±0.0)	0.2 (±0.0)	0.8
	CEC (meq/100 g)	46.7 (±0.9)	39.4 (±5.6)	1.3	48.3 (±1.8)	40.6 (±4.6)	1.6
	Clay (%)	28.7 (±2.4)	31.3 (±1.3)	−0.1	24.7 (±1.3)	36.7 (±0.7)	−8.0**
	Silt (%)	30.0 (±1.2)	36.0 (±0.0)	−5.2*	33.3 (±1.3)	34.7 (±0.7)	−0.9
	Sand (%)	41.3 (±3.3)	32.7 (±1.3)	2.4*	42.0 (±0.0)	28.7 (±0.7)	20.0**
Mid slope	pH	6.0 (±0.1)	6.3 (±0.1)	−.2.6*	6.0 (±0.2)	6.6 (±0.1)	−3.0*
	OC (%)	3.7 (±0.4)	2.9 (±0.4)	1.6	2.8 (±0.2)	2.3 (±0.4)	1.2
	Available P (ppm)	4.4 (±1.7)	8.0 (±3.7)	−0.9	6.4 (±3.0)	4.1 (±0.9)	0.7
	Total N (%)	0.3 (±0.0)	0.3 (±0.0)	1.7	0.3 (±0.0)	0.2 (±0.0)	0.7
	CEC (meq/100 g)	46.1 (±0.4)	43.7 (±2.7)	0.8	44.7 (±0.9)	40.8 (±7.5)	0.5
	Clay (%)	29.3 (±5.3)	23.3 (±3.5)	0.9	38.7 (±8.9)	24.0 (±3.0)	1.5
	Silt (%)	32.0 (±4.6)	32.7 (±1.8)	−0.1	22.7 (±10.3)	32.0 (±2.3)	−0.9
	Sand (%)	38.7 (±2.7)	44.0 (±3.1)	−1.3	38.7 (±3.3)	44.0 (±5.0)	−0.9
Foot slope	pH	6.1 (±0.1)	6.5 (±0.1)	−3.6*	6.1 (±0.1)	6.7 (±0.0)	−7.6**
	OC (%)	3.8 (±0.1)	2.4 (±0.4)	3.0*	3.0 (±0.3)	1.8 (±0.3)	3.1*
	Available P (ppm)	3.5 (±1.4)	3.8 (±1.3)	−0.1	3.7 (±0.7)	3.2 (±0.8)	0.5
	Total N (%)	0.4 (±0.0)	0.2 (±0.1)	3.0*	0.3 (±0.0)	0.2 (±0.0)	4.2*
	CEC (meq/100 g)	47.7 (±5.1)	40.5 (±1.1)	1.4	46.4 (±1.7)	43.1 (±9.4)	0.5
	Clay (%)	24.7 (±1.8)	18.7 (±1.3)	2.7*	23.3 (±3.5)	20.7 (±1.8)	0.7
	Silt (%)	32.7 (±4.4)	32.7 (±2.4)	0.0	31.3 (±1.7)	34.0 (±0.0)	−1.5
	Sand (%)	42.7 (±2.9)	48.7 (±3.7)	−1.3	45.3 (±1.8)	45.3 (±1.8)	0.0
Site*	pH	6.1 (±0.1)	6.4 (±0.1)	−4.9*	6.1 (±0.1)	6.6 (±0.1)	−6.7**
	OC (%)	3.3 (±0.3)	2.9 (±0.3)	1.3	2.7 (±0.2)	1.9 (±0.2)	3.1**
	Available P (ppm)	5.2 (±1.4)	6.1 (±1.4)	−0.4	4.0 (±1.1)	3.5 (±0.4)	0.4
	Total N (%)	0.3 (±0.0)	0.3 (±0.0)	1.8	0.3 (±0.0)	0.2 (±0.0)	2.6*
	CEC (meq/100 g)	46.8 (±1.5)	41.2 (±1.9)	2.3*	46.5 (±0.9)	40.9 (±3.7)	1.4
	Clay (%)	27.6 (±1.9)	24.4 (±2.2)	1.1	28.9 (±3.7)	27.1 (±2.7)	0.4
	Silt (%)	31.6 (±1.9)	33.8 (±1.0)	−1.0	29.1 (±3.5)	33.6 (±0.8)	−1.2
	Sand (%)	40.9 (±1.6)	41.8 (±2.8)	−0.3	42.0 (±1.5)	39.3 (±3.1)	0.8

[*] Site refers to compilation of data based on the aggregated data (i.e., without considering landscape position; N = 9).

considerable (14%) difference between the exclosure and adjacent grazing land in organic carbon content was observed. In the 15- to 30-cm depth, the exclosure displayed significantly ($p < 0.05$) higher organic carbon and nitrogen content than the adjacent grazing land (Table 6). At both depths, the grazing land displayed significantly higher soil pH than the exclosure.

The influence of landscape positions on soil properties was not consistent. For example, at both depths, significant differences in soil organic carbon and nitrogen content between the exclosure and adjacent grazing land were observed at foot slope

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position, while differences at mid and upper slope positions were not significant (Table 6). At each landscape position and soil depth, the grazing land displayed significantly higher soil pH than the exclosure (Table 6).

Higher organic matter, nitrogen and phosphorus content were detected in the 0- to 15-cm depth compared to the values in the 15- to 30-cm depth in exclosure. Differences in these soil properties between the two depths in exclosure were not significant. However, significant difference in soil organic carbon between the two depths was detected in the grazing land.

4. Discussion

The improvements in soil properties (Table 6) and restoration of degraded vegetation (Tables 2, 4, and 5) after four years of the establishment of the exclosure demonstrate that exclosures could be one option to restoring degraded landscapes within short period of time. Also, it is an indication that exclosures could contribute to both peoples' livelihood and environmental quality. In this line, several studies in eastern and horn of Africa (e.g., Metzger et al., 2005; Yayneshet, 2011; Chirwa, 2014; Wairore et al., 2015; Selemani, 2015), China (e.g., Park et al., 2013; Rong et al., 2014) and elsewhere in the world (e.g., Al-Rowaily et al., 2015) have shown that degraded semi-arid vegetation can be restored in relatively short time following the establishment of exclosures on communal grazing lands. Chirwa (2014) elaborated that halting deforestation and forest degradation rates in Africa is key to improve the livelihood of rural communities and adapt to climate change.

The considerable (49%) difference between the exclosure and adjacent grazing land in aboveground biomass (Table 4) and vegetation composition (Table 2) could be explained in two ways. First, exclosure land management improves soil properties (Table 6), which consequently supports the restoration of native vegetation and accumulation of aboveground biomass. Second, free grazing in the adjacent communal grazing land aggravates soil and vegetation degradation. This in turn negatively affects vegetation restoration and accumulation of aboveground biomass. A study in Pakistan (Qasim et al., 2017) has shown that aboveground vegetation biomass significantly increased in 16-year old exclosures when compared to grazed site. Similarly, a study in Ethiopia (Yayneshet, 2011) reported a two-fold increase in aboveground biomass after 8-years of exclosure establishment. A study in China (Rong et al., 2014) has shown that excluding sheep grazing from desert steppe for 8 years approximately tripled the biomass of standing vegetation, especially the shrub component.

Degraded ecosystems are not capable of providing many services which are crucial for human life. The maintenance, restoration, and sustainable use of ecosystems therefore form the basis of "nature-based approaches" to climate change mitigation and adaptation (Naumann et al., 2014). A study in south Africa (Petz et al., 2014) highlighted that the provision of ecosystem services is related to land management as unmanaged, pristine ecosystems provide a different mix of ecosystem services than ecosystems recently restored or managed as grazing lands. This study further elaborated that nature conservation and restoration is the best for the sufficient provision of multiple ecosystem services. In this line, the considerable (49%) increases in aboveground biomass following the establishment of exclosures indicates that exclosure land management could be a viable option to mitigate of and adapt to climate change through reducing greenhouse gas emissions. For example, restoring degraded vegetation through long-term conservation approaches such as exclosures leads to increased carbon absorption or sequestration (Powers et al., 2011; Mekuria et al. 2011b, 2015). Also, the improvement in species richness, diversity, and evenness (Table 4) is key to fostering other important ecosystem services, such as the conservation of native species, which in turn supports nutrition and building of the livelihood of local communities.

The results demonstrated that landscape position influenced the restoration of vegetation and aboveground biomass (Table 5). The better vegetation composition and productivity at foot slope position in exclosures compared to mid- and upper-slope positions (Table 5) could be attributed to the influence of landscape position in restoring soil properties and the existence of big size trees. For example, the foot slope receives overland flow and deposition from the upper and mid slope positions (Mekuria et al., 2009), which leads to the accumulation of fertile topsoil. This in turn support the fast growth of trees and grasses. However, upper slope position displayed better vegetation composition and biomass in communal grazing land compared to the mid- and foot-slope positions (Table 5). This could be attributed to the easy access of livestock in foot slope position, which results in vegetation and soil degradation.

The observed improvement in soil properties (Table 6) following the establishment of exclosures could be attributed to organic inputs from the restored vegetation and protection of exclosures from free grazing. A study in Kenya (Mureithi et al., 2014) demonstrated increases in the soil organic carbon, total nitrogen and microbial biomass contents and stocks following the establishment of exclosures. This study further explained that exclosures can have the potential for the restoration of soil quality through range rehabilitation. Similarly, a study conducted in east African savannah ecosystem (Yusuf et al., 2015) has shown that soil organic carbon (SOC) and total soil nitrogen stocks (TSN) are affected by grazing, but the magnitude is largely influenced by woody encroachment and soil texture. This study suggested that improving the herbaceous layer cover through a reduction in grazing and woody encroachment restriction are the key strategies for reducing SOC and TSN losses and, hence, for climate change mitigation in semi-arid rangelands.

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Our results have shown that exclosure land management can support to diversify the livelihood options of local communities, as most of the regenerated woody species are economically important (Fig. 4), and once vegetation is restored, income generating activities can be integrated. In this line, a study in Kenya (Nyberg et al., 2015) indicated that the adoption of exclosures as degraded land restoration option has enabled agricultural diversification, e.g. increased crop agriculture, poultry production and the inclusion of improved livestock. According to this same study, following the use of exclosures, livelihoods have become less dependent on livestock migration, are increasingly directed towards agribusinesses and present new opportunities and constraints for women. Experiences of seven different African countries (Kumar et al., 2015) demonstrated that the restoration of degraded landscapes support the local communities to harvest diverse products, ranging from non-timber forest products (NTFPs) used for food to non-edible forest products, fodder for livestock, small wildlife, and crops including cereals and legumes.

5. Conclusions

Establishing exclosures on degraded lands could support the restoration of degraded native vegetation and soil properties, which consequently enhance the ecosystem services that can be obtained from degraded lands. Exclosures could support the efforts to mitigate and adapt to climate change, as establishing exclosure on degraded lands leads to increased carbon absorption or sequestration. Our results indicate that exclosure land management can support to diversify the livelihood options of local communities, as most of the regenerated woody species are economically important, and once vegetation is restored, income generating activities can be integrated.

Declarations

Author contribution statement

Wolde Mekuria: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Menale Wondie, Tadele Amare, Asmare Wubet, Tesfaye Feyisa, Birru Yitaferu: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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