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Research article

Impact of exclosures on woody species diversity in degraded lands: the case of Lemo in Southwestern Ethiopia

Abebe Fikadu [a,*], Mekuria Argaw [b]

[a] Department of Natural Resources Management, Arba Minch University, Ethiopia
[b] Center for Environmental Science, Addis Ababa University, Ethiopia

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ABSTRACT

Exclosures are popularly applied to rehabilitate degraded lands and to gradually restore the productive potential of the land in the long term. This study was conducted to examine the impact of removing human and livestock interference from a degraded land to allow natural recuperation for extended period of years. The aim was to assess the trend of changes in the composition, diversity and structure of the woody component of the vegetation within the exclosures. Degraded lands with different years of exclosure were compared with adjacent open grazing lands under similar environmental conditions. A Systematic transect sampling method was employed to collect vegetation data in sampling quadrat plots, each with a size of 20 m × 20 m, evenly distributed along parallel transect lines. All the woody plant species in each plot were identified and measured for DBH and height. The species diversity and density were analyzed using standard indices. The structural pattern and regeneration status of the woody vegetation was described using size class distribution plots. The findings showed that the woody vegetation composition significantly varied between exclosures and open grazing land. There was significantly ($P < 0.05$) higher diversity, richness and stand density of the woody species in the exclosures than in the open grazing lands. The size class distribution of the DBH and height of the recorded species exhibited an inverted "J" shape pattern suggesting a healthy regeneration status of the important species, while the distribution pattern in the open grazing lands revealed irregular and less interpretable pattern. This study evidently showed exclosures can successfully contribute to biodiversity restoration in highly degraded lands, perhaps due to improvements in the important micro-climate conditions such as moisture and organic matter.

1. Introduction

Land degradation is a continuous worsening of the loss of productive capacity of the land (Le et al., 2012), which comprises all factors that diminish the capacity of the land to function and to produce ecosystem goods and services (Hurni et al., 2010). It is a global problem that is largely driven by anthropogenic practices (Hurni et al., 2010; Conacher, 2009) such as deforestation, overgrazing, over-cultivation, fertilization and nutrient depletion (Nedessa et al., 2005). Unsustainable utilization of the land resources ultimately impairs people's livelihoods, the environment and ecosystem functioning (Tefera, 2002; UNEP, 2009; Nedessa et al., 2005).

Over the last decades, the extent and severity of land degradation at the global scale has been increasing by about 20%, 30% and 10% in cultivated lands, forests and in grasslands, respectively (Bai et al., 2008). According to Bojö and Cassells (1995), the total degraded land in the Ethiopian highlands was projected to have reached 100,000 km^2 by 2010, However, a study conducted by Nkonya et al. (2016) revealed that extent of degraded land has already been doubled by 2006, which was reported as 228,000 km^2 in that study. Similarly, Dejene (2003) reported that 50% of the highlands were significantly eroded, resulting in a severe ecological and socioeconomic challenges on the environment and the livelihoods of rural communities.

In the past, in response to the ever increasing trend of land degradation, government and non-government development organizations have been implementing various kinds of sustainable land management practices (SLM) in the Ethiopian highlands (Nedessa et al., 2005). Among the many practices, Exclosure have been widely implemented and showed promising results in rehabilitating degraded lands through natural regeneration with minimum inputs and investment (Mengistu, 2002; Birhane, 2002; Giday, 2002). Exclosures are land areas that have lost significant level of the productive capacity and are set aside for natural

* Corresponding author.
E-mail address: abeyene2000@gmail.com (A. Fikadu).

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regeneration by permanently removing human and livestock interference during the course of rehabilitation (Nedessa et al., 2005). The technique is passive and a low-investment land management approach in which restoration of biomass, accumulation of soil organic matter and moisture is maximized through the natural succession of the woody and non-woody vegetation. Unlike an active restoration approach, exclosures rely on the self-regenerating potential of ecosystems following the removal of degradation driving agents (Mengistu et al., 2005). As a result, there has been growing trend of degraded areas being placed under exclosures not only in the northern highlands but also in the central and several parts of the southern regions of Ethiopia (Birhane, 2002).

On top of the benefits to revitalize the productive capacity of the land, exclosures immensely contribute to restoration of *in situ* biodiversity in the landscape and vegetation ecosystems. However, scientific studies on the role of exclosure for the restoration of the composition and diversity of woody vegetation are scanty (Birhane, 2002). The knowledge on diversity and structure of the woody vegetation is essential for planning the management of degraded forest ecosystems to maximize the benefits from the ecological goods and services. The objective of this study was to analyze the impact and contribution of exclosures in restoring the composition, diversity and structure of the woody vegetation in selected degraded lands that have been set aside for natural recuperation. Besides, the findings are intended to add knowledge to the scientific understanding of the land management practice so as to amplify its application and maximize the benefits from the passive low-cost restoration approach.

2. Materials and methods

2.1. Study area description

The study was conducted in two purposely selected exclosures in the Lemo district of the Hadiya zone in Southern Ethiopia. The geographical location is between 7°42′N to 7°75′N and 37°80′E to 38°07′E with an altitude range of 2058 and 2140 m.a.s.l. The mean annual rainfall is about 1346 mm with mean maximum and minimum temperatures of 18.8 and 15.1 °C, respectively (Melese, 2014: Berihanu, 2010).

Two separate degraded land areas with different years of exclosure from human and livestock interference (one for 10 years and the other for 24 years) were studied and compared with adjacent open grazing lands (Figure 1). The exclosures were set aside for protection in 1994 and 2008, respectively. Before implementing the exclosure, both the protected and open grazing lands were under similar state of degradation, particularly vegetation loss, soil erosion and uncontrolled extraction of biomass by people and livestock. The exclosures were implemented through a participatory process in consultation with local communities and administered by a community bylaw as an instrument of exclusion of interference by people and livestock. Whereas the open grazing areas still remain as communal grazing lands with an open access to local community members for grazing of Livestock (e.g., cattle, shoats, equines) and biomass removal (fuel wood, poles, brushes, litter, grass, etc…). The total areas of the protected lands cover 107 ha (10 years) and 51 ha (24 years). The corresponding adjacent open grazing lands cover 72 ha and 33 ha, respectively.

2.2. Comparative analysis approach

We applied the space-for-time substitution approach (Fukami and Wardle, 2005), which is used to detect changes in vegetation composition, diversity, richness and density after conversion of degraded land to exclosure. This approach, which has been widely applied in ecology, is a method that is used to extrapolate temporal dynamics of vegetation succession by comparing multiple sites of different years of protection after disturbance or land use change in a landscape. The inherent assumption in this study is that the exclosure and the paired adjacent open grazing lands have comparable initial conditions so that changes in vegetation composition, richness and diversity are a consequence of the establishment of exclosure or the removal of the human and livestock interference. As a result, the protected exclosures and adjacent open grazing lands were purposively selected within the same landscape and similar environmental conditions.

2.3. Vegetation sampling

A standard systematic transect sampling method was employed following Muller-Dombois (1974). Parallel transect lines were laid crossing each study site from edge to edge (Birhane et al., 2007). The transect lines were laid at a distance of 50 m from the edges to avoid the effects of disturbances. Transects were laid at 200 m apart.

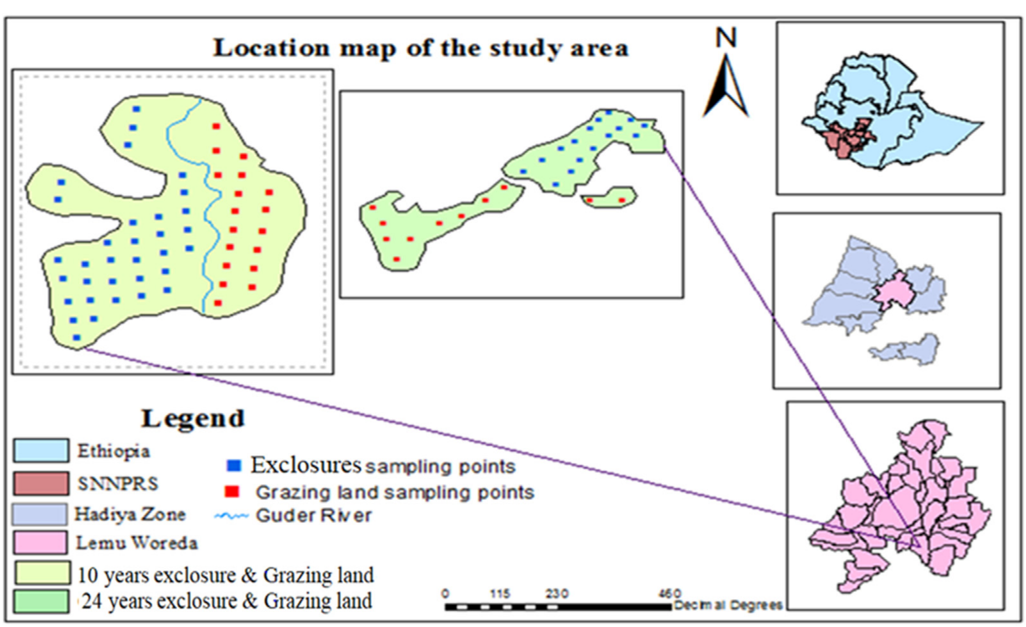

Figure 1. Location map of the study area and sampling points in the exclosures (Blue dots) and in the open grazing lands (Red dots).

Vegetation sampling was done in a sampling quadrat of 20 m × 20 m in the year 2018. All sampling quadrats were distributed along the transects at a distance of 150 m interval between quadrats. The first sampling quadrat on each transect was laid randomly. A total of 78 sampling quadrats (33 from the 10 years exclosure and 19 from its adjacent open grazing land; 16 from the 24 years exclosure and 10 from its adjacent open grazing land) were used for vegetation sampling. The number of quadrat plots was proportionally distributed based on the area coverage of each of the protected and open grazing lands (Mengistu et al., 2005).

The quadrats were marked using plastic ribbon, four wooden pegs and compass. In each quadrat, the types and number of all individuals of the woody species were identified, counted and recorded by their local and/or scientific names (Azene Bekele, 2007; Birhane et al., 2007). The height and diameter of trees, shrubs, saplings and seedlings of the woody species were measured using a marked measuring stick and diameter tape, respectively. The diameter measured at breast height (DBH) for trees and diameter at stump height (DSH) for shrubs and saplings (Getseselassie, 2012: Mengistu et al., 2005). Individuals with a height ≥3 m and DBH >2.5 cm were considered as trees/shrubs, individuals <2 m in height and DBH <2.5 cm were recorded as saplings, and height less than 1 m were taken as seedlings, for which only the total numbers were counted (Birhane et al., 2007; Lai et al., 2009).

Herbarium specimens were collected for those plants which were not identified in the field. Specimens were properly dried in a plant press and submitted to be identified at the National Herbarium in Addis Ababa University, where voucher specimens were deposited. The names of the plant species were identified as per the published Flora of Ethiopia and Eretria (Edwards et al., 1995, 1997; Hedbergs et al., 2004, 2006).

2.4. Vegetation diversity, richness and structure analysis

Shannon Wiener diversity and evenness indexes were computed to describe species diversity, richness and the population size of each of the species present. Shannon Wiener diversity index is the most popular measure of species diversity because it accounts both for species richness and evenness, and it is not affected by sample size (Erenso et al., 2014). The Shannon diversity and evenness indexes were calculated as;

$$H' = -\sum_{i=1}^{s} pi \ln pi \tag{1}$$

$$Evenness\ (J) = \frac{H'}{H'max} = \frac{-\sum_{i=1}^{s} pi \ln pi}{\ln s} \tag{2}$$

Where:

H' = Shannon diversity index
S = the number of species
Pi = the proportion of individual abundance of the i^{th} species
ln = log base
H'max = ln S
ln S = the natural logarithm of the total number of species in each community (Shannon and Weaver, 1949).

Evenness (equitability) describes the relative abundance of the different species in an area. Species evenness that measures the equity of species in a given sample area is represented by 0 and 1, where 0 indicates the abundance of few species and 1 shows equally abundance of all species in the area (Whittaker, 1965).

Sorensen's similarity coefficient was calculated using the following formula to determine similarities between exclosures and open grazing lands (Sorensen, 1948):

$$SC = \frac{2\boldsymbol{a}}{2\boldsymbol{a} + \boldsymbol{b} + \boldsymbol{c}} \tag{3}$$

where,

$\boldsymbol{a}$ = number of species common to both lands.
$\boldsymbol{b}$ = number of species present in the first and absent from the second.
$\boldsymbol{c}$ = number of species present in the second habitat and absent from the first.

Species densities, height, and diameter at breast height (DBH) were used for description of the vegetation structure. The population structures were analyzed using histograms with the grouped diameter classes and height. It was constructed by using the density of individuals of each species (Y-axis) categorized into seven diameter classes (X-axis), i.e. class 1 = < 2 cm; class 2 = 2–5 cm; class 3 = 5–7.5 cm; class 4 = 7.5–10 cm; class 5 = 10–15 cm; class 6 = 15–20 cm; class 7 = >20 cm. The purpose of using size class distributions in diameter at breast height (DBH) is to investigate the regeneration status of the woody plant species (Peters and Mundial, 1996).

The structure parameters of the woody species were calculated and summarized in a spreadsheet using the following formulas;

$$\text{Density} = \left(\frac{\text{Total number of stems of all trees}}{\text{Sample size in hectare}}\right) \tag{4}$$

$$\text{Relative density} = \left(\frac{\text{Number of individuals of tree species}}{\text{Total number of individuals}}\right) \times 100 \tag{5}$$

$$\text{Frequency} = \left(\frac{\text{Number of plots in which a species occur}}{\text{Total number of plots laid out in the study site}}\right) \times 100 \tag{6}$$

$$\text{Relative frequency} = \left(\frac{\text{Frequency of tree species}}{\text{Frequency of all species}}\right) \times 100 \tag{7}$$

$$\text{BA} = \frac{\pi D^2}{4} \tag{8}$$

where;

BA = basal area in m^2 per hectare.
D = diameter at breast height in meter.
π = 3.14

$$\text{Relative Dominance} = \frac{\text{Basal area of a species}}{\text{Total basal area of all species}} \times 100 \tag{9}$$

The relative ecological importance of a given woody species at a particular site can be indicated by Important Value Index (IVI), and it was determined from the summation of the relative values of density, frequency and dominance of each woody species (Asigbaase et al., 2019).

2.5. Statistical analysis

The vegetation data of the exclosures and open grazing lands were compared to examine the impact of the exclosure on woody species diversity, structure and composition. Descriptive statistics and ANOVA tests were done for the data set from the two adjacent sites using SPSS software version 21. The mean separation test was done using the least significant difference (LSD) method at ($P \le 0.05$) probability level (Gomez and Gomez, 1984).

3. Results

3.1. Composition and diversity of the woody vegetation

A total of 74 woody species representing 40 families were recorded from the entire study sites. A total of 67 species (from 38 families) and 18 species (from 16 families) were recorded in 10 years exclosure and its adjacent open grazing land, respectively. Similarly, a total of 46 species (from 31 families) and 17 species (from 13 families) were recorded from the 24 years exclosure and its adjacent open grazing land, respectively (Tables 1 and 2).

Among the total families recorded, 18 families were common to both exclosures and the open grazing lands whereas the remaining 22 families were recorded only in the exclosures. *Fabaceae* family was represented by nine species, which is the most dominant family followed by *Flacourtiaceae, Myrtaceae* and *Rosaceae* families each represented by three species. The remaining families were represented by either one or two species in both exclosures and open grazing lands (Table 2). From the total number species recorded in all the sampling plots, 64 species were indigenous to Ethiopia while the remaining 10 species were exotic (Table 1).

Considerable difference in the species composition of the woody vegetation was observed between the exclosures and the open grazing lands. The Sorensen's similarity coefficient (SSC) showed a high variability in species compositions with values varying from 0.41 to 0.77 (Table 3). The SSC values for the exclosures showed high similarity while values for the open grazing lands revealed dissimilarity in species composition (Table 3).

3.1.1. Richness, diversity and evenness of woody species

The woody species richness and diversity significantly varied among the exclosures and the open grazing lands ($p < 0.05$). The exclosures showed high level of species diversity, richness and evenness compared to the open grazing lands. However, despite the difference in number of years of protection from interference, there was no significant variation between the two exclosures (Table 4). The trend generally suggests that the longer the period of exclosures, the higher the likely increase in species richness, diversity and evenness. Compared to the open grazing lands, the indices for the 24 years exclosure were found to be twice as high as those of the open grazing lands (Table 5).

3.2. Density and frequency of the woody species

The exclosures exhibited higher density of woody species than the open grazing lands. The 24 years exclosure showed a density of 3324 individuals per hectare. The proportion of tree, saplings and seedlings were 23.1%, 23% and 53.8%, respectively. The open grazing land showed 118 individuals per hectare, in which trees, saplings and seedlings constituted 52.54%, 47.5% and 9.6%, respectively. Similarly, 2792 individuals per hectare were recorded under the 10 years exclosure with 23.1%, 31.5% and 45.5% proportion of trees, saplings and seedlings, respectively, while 482 individuals were recorded in the open grazing land. Of these, the trees, saplings and seedlings accounted for 51.5%, 38.8% and 9.7%, respectively. Proportionally, the density of seedlings in exclosures was greater than saplings and trees. Based on their habit, higher density of woody species was also recorded under exclosures than open grazing lands. Shrubs were the dominant life form in both exclosures and open grazing lands. The 24 years exclosure exhibited relatively more tree density than the 10 years exclosure whereas more shrubs were recorded under 10 years exclosure (Table 6).

The density and frequency of individual species were higher in exclosures than the open grazing lands. *Dodonaea angustifolia* was the most dominant species in density in the 10 years exclosure followed by *Euclea divinorum, Carissa spinarum, Acacia saligna* and *Myrsine africana.* In the 24 years exclosure, *Carissa spinarum* was the most densely populated species followed by *Dodonaea angustifolia* and *Acacia saligna.* Similarly, *Dodonaea angustifolia, Euclea divinorum, Carissa spinarum, Myrsine africana, Acacia seyal* and *Juniperus procera* occurred most frequently in the 10 years exclosure in that order. These species accounted more than 50% of the frequency of occurrence. Likewise, *Carissa spinarum, Dodonaea angustifolia, Juniperus procera, Acacia decurrens, Syzygium guineense* and *Acacia abyssinica* occurred most frequently in the 24 years exclosure. In the open grazing land, the most frequently occurred woody species was *Euclea divinorum* followed by *Dodonaea angustifolia* and *Carissa spinarum* (Table 7).

3.3. Population structure of the woody species

The highest numbers of individuals were recorded in the diameter class of below 5 cm, in both the exclosures and the open grazing lands. Exclosures exhibited a continuous decline in number of individuals from the lower to the high diameter classes. However, the size distribution in the open grazing lands showed an irregular pattern of distribution showing no apparent representation of some of the species in the structure. Unlike in the open grazing lands, the size class distribution of the DBH in the exclosures exhibited an inverted “J” shaped pattern (Figure 2), showing good representation of the woody species in the seedlings and saplings signaling good regeneration status.

Similarly, the lower height classes in both exclosures and open grazing lands were represented by the highest numbers of individuals. The distribution pattern showed a decrease in number of individuals with increase in height class. However, a linear decline has been observed in the exclosures than the open grazing lands from lower to higher height class distribution. Alike the diameter class, nearly an inverted “J” shaped patterns were also observed in the height class distribution of exclosures (Figure 2). Similar trends of diameter and height class distribution have been observed in both the 10 years and 24 years exclosures. However, the higher diameter and height classes were represented by highest number of individuals in the 24 years than in the 10 years exclosure.

The species *Carrisa spinarum* and *Dodonaea angustifolia* have been largely represented in the regeneration stock of the vegetation in the exclosures and doesn't show any structured pattern in the open grazing lands. For majority of the species, the largest numbers are concentrated in the lowest DBH class of 1–2 cm. The inverted “J” shaped pattern was observed for most of the species in the exclosures while the species in the

Table 1. Total number of Genera, species and families recorded in the exclosures and open grazing lands.

Land use	Species	Genera	Families	To Ethiopia	
				Indigenous	Exotic
10 years exclosure	67	53	38	57	10
24 years exclosure	46	38	31	40	6
OGL 10	18	16	16	17	1
OGL 24	17	14	13	15	2
Total	**74**	**56**	**40**	**64**	**10**

The OGL 10 was compared with the 10 years exclosure and the OGL 24 was compared with the 24 years exclosure.
OGL 10 = Open grazing land adjacent to 10 years exclosure, OGL 24 = Open grazing land adjacent to 24 years exclosure.

Table 2. Total number of species recorded in each family in the exclosures and open grazing lands.

Family	Number of species per family				
	10 years exclosure	OGL 10	24 years exclosure	OGL 24	Total
Fabaceae	9	2	8	3	9
Aloaceae	1	0	0	0	1
Poaceae	1	0	0	0	1
Melianthaceae	1	0	1	0	1
Arecaceae	2	0	1	0	2
Capparidaceae	1	0	0	0	1
Apocynaceae	1	1	1	1	1
Rutaceae	1	0	1	0	1
Euphorbiaceae	3	1	1	1	3
Combretaceae	1	0	0	0	1
Cupressaceae	2	0	2	1	2
Sapindaceae	1	1	1	1	1
Flacourtiaceae	3	1	1	0	3
Ericaceae	1	1	1	0	1
Myrtaceae	3	1	3	2	3
Ebenaceae	1	1	1	0	1
Moraceae	2	1	1	2	2
Proteaceae	1	0	0	0	1
Tiliaceae	1	0	1	0	1
Apiaceae	1	0	1	0	2
Guttiferae	2	0	1	0	2
Oleaceae	2	0	0	0	2
Acanthaceae	1	0	0	0	1
Verbenaceae	1	0	1	0	1
Myrsinaceae	2	1	1	1	3
Celastraceae	3	2	2	1	3
Oleaceae	2	0	1	0	2
Oliniaceae	1	1	1	1	1
Santalaceae	1	1	1	1	2
Phytolaccaceae	1	0	0	0	1
Podocarpaceae	1	0	0	0	1
Lamiaceae	0	1	1	0	2
Proteaceae	1	0	0	0	1
Rosaceae	3	0	1	0	3
Rubiaceae	2	0	2	1	2
Rhamnaceae	2	0	2	0	2
Anacardiaceae	1	0	0	0	1
Pittosporaceae	2	1	2	0	2
Asteraceae	2	1	3	1	3
Commelinaceae	0	0	2	0	1
Total					
40	**67**	**18**	**46**	**17**	**74**

OGL 10 = Open grazing land adjacent to 10 years exclosure, OGL 24 = Open grazing land adjacent to 24 years exclosure.

Table 3. Sorensen's similarity coefficient (SSC) of exclosures and open grazing lands.

	Open grazing land		Exclosure	
	OGL 10	OGL 24	10 years	24 years
OGL 10	1			
OGL 24	0.63	1		
10 years exclosure	0.41	0.39	1	
24 years exclosure	0.44	0.44	0.77	1

OGL 10 = Open grazing land adjacent to 10 years exclosure, OGL 24 = Open grazing land adjacent to 24 years exclosure.

Table 4. Summary of ANOVA results for species richness and diversity in relation to exclosures and duration of exclosure.

Source of variation	df	Richness		Diversity	
		MS	p	MS	P
Land use types (Open grazing land Vs Exclosure)	1	520.51	0.001	8.89	0.001
Exclosure duration	1	1.22	0.850	0.16	0.475

df = degree of freedom, MS = mean square, p = significance level.

Table 5. Species richness, evenness, and Shannon-Wiener Index (H) in the exclosures and open grazing lands.

Land use	Species richness	Species evenness	Species diversity (H′)
10 years exclosure	65	0.74	3.1
24 years exclosure	46	0.84	3.21
OGL 10	18	0.69	1.99
OGL 24	17	0.72	1.96

OGL 10 = Open grazing land adjacent to 10 years exclosure, OGL 24 = Open grazing land adjacent to 24 years exclosure.

Table 6. Seedling, Sapling and tree density and their proportion in exclosures and the open grazing lands (stem/hectare).

Land use	Density (N/ha)			Total	Proportion (%)			N/ha	
	Seedlings	Saplings	Tree		Seedlings	Saplings	Tree	Shrub	Tree
10 years exclosure	1269	879	644	2792	45.5	31.5	23.1	830	703
24 years exclosure	1791	765	768	3324	53.8	23.1	23.1	792	737
OGL 10	47	187	248	482	9.7	38.8	51.5	374	60
OGL 24	9	56	62	118	9.6	47.5	52.5	115	93

OGL 10 = Open grazing land adjacent to 10 years exclosure, OGL 24 = Open grazing land adjacent to 24 years exclosure.

open grazing lands demonstrated no regular pattern that can show healthy representation (Figure 3).

The diameter class distribution of other species such as *Euclea divinorum, Syzygium guineense*, *Acacia abyssinica* and *Juniperus procera* were comparatively represented by a relatively high number of individuals in the diameter class of 1–2 cm declining towards the large size classes. However, in the 24 years exclosure, *Syzygium guineense* and *Acacia abyssinica* were represented by large number of individuals in the diameter class of 5–7.5 cm and 10–15 cm, respectively. The population structure of these species followed bell shaped pattern of distribution showing that their regeneration is hampered by some unexplained factors. Two species, such as *Acacia abyssinica* and *Juniperus procera* were represented by individuals in all diameter classes (1 to >20 cm) in the exclosures suggesting that they are in relatively healthy trend of succession (Figure 3).

3.3.1. Important value index (IVI)

The IVI (important value index) of most woody species were high in the exclosures than in the open grazing lands. These were well represented by *Dodonaea angustifolia* (IVI = 24.1), *Euclea divinorum* (IVI = 23.79), *Carissa spinarum* (IVI = 19.24) in the 10 years exclosure. These same species recorded IVI values of 51.57, 42.51 and 42.93, respectively in the 10 years open grazing land. The relative density and frequency of the species in the exclosures and the open grazing lands attributed for the high IVI values. Some of these species include *Carissa spinarum* (72.13), *Dodonaea angustifolia* (24.51) and *Juniperus procera* (23.28), respectively (Table 7).

4. Discussion

The results from the findings demonstrated the positive role of exclosures for the restoration of woody vegetation diversity in degraded lands if driving factors such as livestock grazing and biomass extraction are removed successfully. The floristic compositions, species richness, diversity, evenness and the population structure in the exclosure reassure the effectiveness of the restoration technique if applied strictly. On the other hand, the practice of free grazing in common lands and uncontrolled removal of woody and non-woody biomass negatively affects the regeneration and growth potential of the surviving plants. Though similar studies, few in number, in the Ethiopian highlands reported similar positive impacts on *in situ* diversity of woody and non-woody plants in exclosures (Mengistu et al., 2005; Mekuria and Yami, 2013; Mekuria et al., 2015; Adem et al., 2020).

Despite the positive impacts, significant improvements in the composition, diversity and richness will require extended period of time (longer years of protection) after establishment. It has been proved that these vegetation parameters, including the diversity traits, were observed to be in the 24 years exclosure than in the 10 years exclosure. Hence, it can be inferred that time is a critical factor for effective and sustainable restoration of vegetation diversity in area exclosures (Jeddi and Chaieb, 2010; Mengistu et al., 2005; Mekuria and Yami, 2013). Contrary to the current finding, Oba et al. (2001) reported that in a semi-arid part of Kenya, the species richness observed to decline over the increasing period of exclosures following an early peak. Though not of the woody species, Angassa and Oba (2010) reported a decline of the species richness in the herbaceous vegetation with increasing years of exclosure. In another study by Oba et al. (2001), herbaceous and pioneer species richness were observed to decline in the abundance of shrub and tree species. The Shannon diversity (H') and Evenness (J) indices suggest the longer the exclosure period is the more diverse the vegetation will become in the degraded land. These indices consider the number of individual stems of a given species and hence the higher the values showing more diversity.

Table 7. Density and frequency of species in the exclosures and the open grazing lands (N/ha, frequency (%)).

Species Name[a]	Exclosures						Open grazing lands					
	10 years			24 years			OGL 10			OGL 24		
	Den.	Freq.	IVI	Dens.	Freq.	IVI	Dens.	Freq.	IVI	Dens.	Freq.	IVI
Acacia abyssinica Hochst.	15.15	21.21	8.6	29.69	37.5	12	2.78	27.78	13	10	20	34
Acacia decurrens Willd[b]	67.42	33.33	24	110.94	68.75	50	-	-	-	2.5	10	14
Acacia melanoxylon R. Br.[b]	0.76	3.03	0.3	15.63	18.75	5.8	-	-	-	-	-	-
Acacia saligna (Labill.)[b]	130.3	39.39	25	123.44	75	19	-	-	-	-	-	-
Acacia seyal Del.	42.42	51.52	14	18.75	6.25	3.1	9.72	27.78	12	10	30	22
Aloe genus (Aloe spp.)	0.76	3.03	0.6	-	-	-	-	-	-	-	-	-
Arundo donax L.[b]	0.76	3.03	0.3	-	-	-	-	-	-	-	-	-
Bersama abyssinica Fresen.	2.27	9.09	0.9	18.75	31.25	4.3	-	-	-	-	-	-
Borassus aethiopum Mart.	0.76	3.03	0.3	12.5	12.5	2	-	-	-	-	-	-
Caesalpinia decapetala (Roth)[b]	0.76	3.03	0.3	-	-	-	-	-	-	-	-	-
Calpurnia aurea (Ait.) Benth.	0.76	3.03	0.3	12.5	12.5	1.8	-	-	-	-	-	-
Capparis decidua	0.76	3.03	0.4	-	-	-	-	-	-	-	-	-
Carissa spinarum L.	170.45	66.67	19	223.44	93.75	23	108.3	27.78	43	92.5	40	72
Clausena anisata (Willd.) Benth.	3.03	6.06	0.8	4.69	6.25	0.9	-	-	-	-	-	
Clutia abyssinica Jaub. & Spach.	0.76	3.03	0.3	-	-	-	-	-	-	-	-	-
Combretum molle R. Br. ex G. Don.	17.42	15.15	5.7	-	-	-	-	-	-	-	-	-
Croton macrostachyus Del.	9.09	15.15	3.6	25	37.5	5.2	12.5	5.56	6.1	27.5	40	40
Cupressus lusitanica Mill.[b]	6.82	9.09	1.8	10.94	6.25	3	-	-	-	-		-
Dodonaea angustifolia L. f.	210.61	87.88	24	178.13	87.5	22	138.9	38.89	52	22.5	30	25
Dovyalis abyssinica (A. Rich.)	0.76	3.03	0.3	-	-	-	-	-	-	-	-	-
Erica arborea L.	52.27	27.27	6.8	4.69	6.25	0.8	11.11	27.78	10	-	-	-
Eucalyptus camaldulensis[b] *Dehnh.*	18.94	18.18	9.7	67.19	37.5	12	8.33	11.11	43	15	30	42
Eucalyptus globulus Labill.[b]	6.82	12.12	5.1	25	31.25	6.6	-	-	-	-	-	-
Euclea divinorum Hiern	186.36	75.76	24	37.5	25	4.7	84.7	55.56	43	-	-	-
Euphorbia abyssinica Gmel.	0.76	3.03	1	-	-	-	-	-	-	-	-	-
Ficus sycomorus L.	0.76	3.03	0.3	14.06	18.75	2.4	-	-	-	2.5	10	5.6
Ficus vasta Forssk	0.76	3.03	0.3	-	-	-	4.17	11.11	18	2.5	10	8.8
Flacourtia indica (Burm.f.)	9.09	21.21	2.6	6.25	6.25	1.2	2.78	11.11	3.7	-	-	-
Grevillea robusta R. Br.[b]	9.85	15.15	2.7	-	-	-	-	-	-	-	-	-
Grewia ferruginea Hochst. ex A.	3.79	15.15	1.5	7.81	12.5	1.8	-	-	-	-	-	-
Heteromorpha arborescens (Spreng.)	32.58	27.27	4.8	67.19	43.75	8.1	-	-	-	-	-	-
Hypericum quartinianum A.	5.3	9.09	1.1	4.69	6.25	0.8	-	-	-	-	-	-
Hypericum revolutum Vahl	9.85	18.18	2.2	4.69	6.25	0.8	-	-	-	-	-	-
Jasminum abyssinicum Hochets.	4.55	12.12	1.3	48.44	75	0.9	-	-	-	-	-	-
Juniperus procera Hochst.	49.24	54.55	13	-	-	-	-	-	-	7.5	20	23
Justicia schimperiana (Hochst. ex Nees) T. Anders.	5.3	12.12	1.4	20.31	18.75	2.8	-	-	-	-	-	-
Lippia adoensis Hochst. ex Walp.	1.52	6.06	0.6	-	-	-	-	-	-	-	-	-
Maesa lanceolata Forssk.	19.7	33.33	5	26.56	37.5	6.3	-	-	-	10	40	19
Maytenus heterophylla (Eckl)	24.24	48.48	5.7	42.19	6.25	3.4	9.72	33.33	11	5	10	6.8
Maytenus serrata (A. Rich.) Wilczek	31.82	66.67	7.6	20.31	12.5	2.4	5.56	22.22	7.4	-	-	-
Maytenus undata (Thunb.) Blakelock	0.76	3.03	0.3	-	-	-	-	-	-	-	-	-
Myrsine africana L.	109.09	66.67	13	50	37.5	6.4	6.94	27.78	9.1	-	-	-
Olea europaea L.	28.79	54.55	7.2	82.81	56.25	13	-	-	-	-	-	-
Olinia rochetiana A. Juss.	62.12	42.42	9.2	17.19	18.75	2.7	5.56	5.56	3.4	2.5	10	6.1
Osyris quadripartita Decn.	21.21	42.42	5.4	6.25	18.75	1.9	6.94	27.78	10	5	10	6.8
Phytolacca dodecandra L'Her.	1.52	6.06	0.6	-	-	-	-	-	-	-	-	-
Pittosporum abyssinicum Del.	36.36	51.52	7.8	20.31	31.25	5.5	5.56	22.22	7.8	-	-	-
Pittosporum viridiflorum Sims.	4.55	12.12	1.3	-	-	-	-	-	-	-	-	-
Podocarpus falcatus (Thunb.) Mirb.	0.76	3.03	2.6	-	-	-	-	-	-	-	-	-
Premna schimperi Engl.	16.67	45.45	4.6	21.88	37.5	4.5	2.78	5.56	2.1	-	-	-
Protea gaguedi J.F. Gmel.	2.27	3.03	0.7	-	-	-	-	-	-	-	-	-
Prunus africana (Hook.f.) Kalkm.	8.33	9.09	1.3	-	-	-	-	-	-	-	-	-
Psydrax schimperiana (A. Rich)	0.76	3.03	0.3	-	-	-	-	-	-	-	-	-
Rhamnus prinoides L'Herit.	5.3	21.21	2	12.5	43.75	4.3	-	-	-	-	-	-
Rhamnus staddo A. Rich.	3.03	9.09	0.9	7.81	18.75	2	-	-	-	-	-	-

(*continued on next page*)

Table 7 (*continued*)

Species Name[a]	Exclosures						Open grazing lands					
	10 years			24 years			OGL 10			OGL 24		
	Den.	Freq.	IVI	Dens.	Freq.	IVI	Dens.	Freq.	IVI	Dens.	Freq.	IVI
Rhus glutinosa A. Rich.	5.3	12.12	1.4	1.56	6.25	0.6	-	-	-	-	-	-
Rosa abyssinica Lindley.	1.52	6.06	0.6	17.19	50	5.1	-	-	-	-	-	-
Rubus genus (Rubus spp.)	7.58	24.24	2.4	-	-	-	-	-	-	-	-	-
Scolopia theifolia Gilg.	1.52	6.06	0.6	-	-	-	-	-	-	-	-	-
Senna septemtrionalis (Viv.)[b]	4.55	12.12	1.2	6.25	6.25	0.9	-	-	-	-	-	-
Sesbania sesban (L.) Merr.	1.52	3.03	0.4	-	-	-	-	-	-	-	-	-
Syzygium guineense (Wild.) DC.	40.15	21.21	6.2	62.5	43.75	11	-	-	-	50	50	50
Vangueria apiculata K. Schum.	0.76	3.03	0.3	12.5	25	2.8	-	-	-	-	-	-
Vernonia amygdalina Del.	1.52	3.03	0.4	-	-	-	-	-	-	-	-	-
Vernonia schimperi DC.	0.76	3.03	0.3	-	-	-	-	-	-	-	-	-
vernonia auriculifera Hiern.	-	-	-	-	-	-	6.94	11.11	4.5	-	-	-
Vernonia amygdalina Del.	-	-	-	14.06	12.5	1.5	-	-	-	-	-	-
Commelina africana L.	-	-	-	7.81	12.5	0.9	-	-	-	-	-	-
Cyanotis barbata D.Don	-	-	-	6.25	6.25	0.6	-	-	-	-	-	-
Phoenix reclinata Jacq.	-	-	-	1.56	6.25	0.6	-	-	-	-	-	-
Vangueria apiculata K. Schum.	-	-		-	-		-	-		2.5	10	4.58
vernonia auriculifera Hiern.	-	-		-	-		-	-		2.5	10	4.58

Dens. = N/ha, Freq. = Frequency (%), IVI = Important value index (Relative density + Relative frequency + Relative dominance), "–" = absent in the sample plots.
[a] Plant Nomenclature follows (Edwards et al., 1995; Edwards et al., 1997; Hedbergs et al., 2004; Hedbergs I. et al., 2006).
[b] Exotic species.

The abundance of species in the exclosures and open grazing land was greater than 0.6, with higher values of evenness in the 24 years of exclosure (0.84) suggesting that the distribution of individuals of different woody species in exclosures is more equitable than the open grazing lands.

The density of the woody species in the exclosures in the present study significantly exceeded the density of the woody species in the open grazing lands for all size groups (trees, sapling and seedling). Proportionally, the density of seedlings in the exclosures was greater than saplings and trees, which could be considered paramount importance for the successful restoration of the vegetation through good regeneration of the indigenous species in the landscape. The recovery of individuals in exclosures may be triggered by to the improvements in the micro-climate resulting in improved moisture content and organic matter of the soil. This assertion is supported by findings from earlier studies including a study report by Mengistu et al. (2005), who found a higher density of the woody species in exclosures than in open grazing lands. The low density in the open grazing lands could be attributed to the fact that the disturbance factors are still suppressing the regeneration and reinvigoration of the remnant vegetation (Melese, 2014). Another study by Teketay et al. (2018) reported a similar finding of a significant increase in the density of the woody species in exclosures compared to the open grazing lands.

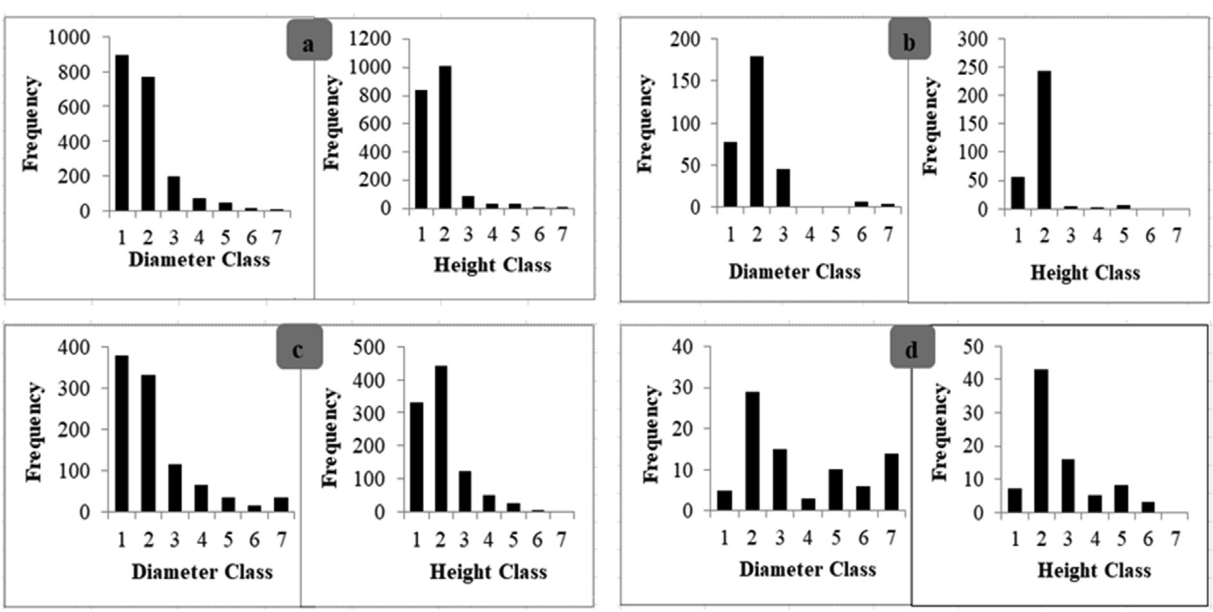

Figure 2. Population structure of woody species in exclosures and open grazing lands (Diameter and height class distribution); (a = 10 years exclosure, b = open grazing land 10 years, c = 24 years exclosures, d = open grazing land 24 years); Diameter classes (1=<2 cm, 2 = 2–5 cm, 3 = 5–7.5 cm, 4 = 7.5–10 cm, 5 = 10–15 cm, 6 = 15–20 cm, 7= >20 cm); Height classes (1=<2 m, 2 = 2–5 m, 3 = 5–7.5 m, 4 = 7.5–10 m, 5 = 10–15 m, 6 = 15–20 m, 7=>20 m).

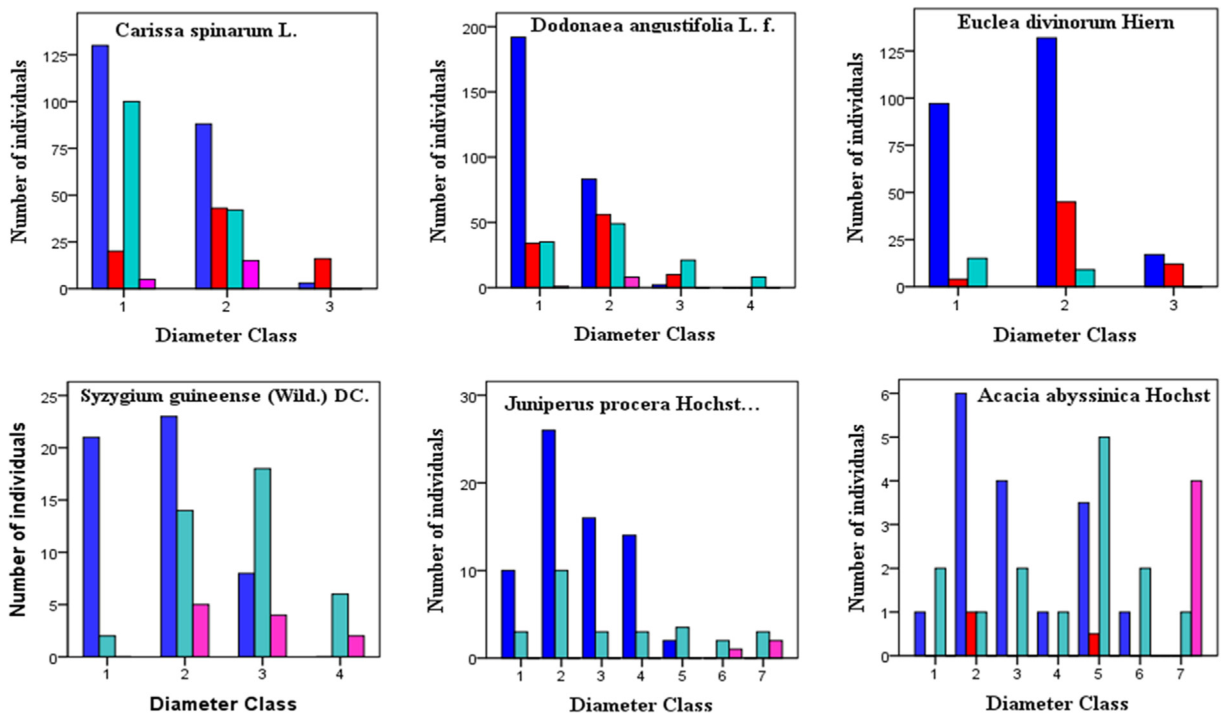

Figure 3. Population structure of some representative woody species in the land use types (Dark blue = 10 years exclosure, Red = OGL 10 years, Light Blue = 24 years exclosure, Pink = OGL 24 years); Diameter distribution classes: DBH class 1 = <2 cm, 2 = 2–5 cm, 3 = 5–7.5 cm, 4 = 7.5–10 cm, 5 = 10-15 cm, 6 = 15–20 cm, 7=>20 cm).

This is an evidence that exclosures improve the environmental conditions including the moisture, organic matter and soil quality that favors plant growth and regeneration.

The ongoing recruitment of woody species population exhibited by lower to higher diameter and height class in exclosures is perhaps due to the contribution of the management practices. On the contrary, on top of unfavorable environmental conditions, the vegetation regeneration is heavily hampered by grazing pressure by livestock and biomass removal for fuel, and associated soil loss through erosion (Yeshitela and Bekele, 2003; Birhane et al., 2007). In agreement with the finding in this study, Mengistu et al. (2005) revealed that exclosures exhibited an inverted "J" distribution pattern of the DBH implying better recruitment performance in the exclosures.

The comparative population structure analysis of some representative woody species revealed that *Carrisa spinarum* and *Dodonaea angustifolia* had a higher number of individuals in lower diameter and height class declining with increasing diameter and height class distribution in exclosures. Unlike other species in the exclosures and open grazing lands, these species exhibited inverted "J" shape pattern of distribution showing stable regeneration of the species in the area. This also indicates that the species are pioneer to the area and good for restoration of degraded land. However, less number of individuals in the lowest diameter class in open grazing lands might be resulted due to the grazing effect of livestock.

The ecological significance of species in a given ecosystem can be described by their important value index (Worku et al., 2012). High IVI values of a species implies more ecologically important than low IVI values of the species (Zegeye et al., 2011). In this study, the IVI value of *Dodonaea angustifolia* and *Carissa spinarum* were highest in both exclosures and open grazing lands as compared to the other species. They could be more ecologically important and play a significant role in the restoration of degraded land.

5. Conclusion

The results of the present study generated empirical evidence that confirm establishing exclosure can be a viable option to restore the composition, diversity, richness and density of woody species in degraded lands. The study showed that exclosure seems to be a promising alternative practice for biodiversity conservation and restoration of degraded land. The floristic composition, density and diversity of woody species as well as the structural composition under exclosures are considerably improved in the study areas. This suggests that successfully protected and managed exclosures improve diversity and associated ecosystem services. Woody species such as *Dodonaea angustifolia*, *Euclea divinorum*, *Carissa spinarum L.*, and some other *Acacia* species were found to be very important for restoration of degraded lands in this study as can be observed from their density, frequency and important value index. Finally, further studies are recommended to investigate for how long degraded land should be closed to bring back the land to the production level.

Declarations

Author contribution statement

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

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

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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