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ORIGINAL PAPER

Effect of exclosure on dryland woody species restoration in northeastern Amhara, Ethiopia

Mubarek Eshetie[1] · Tsegaye Gobezie[2] · Seid Muhie Dawd[2]

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Abstract In Ethiopia, among many restoration efforts to reverse deforestation and land degradation, area exclosure is one of the most common practices to restore secondary forests with assisted natural regeneration. The present study in the Sekota district, northeastern Amhara region, Ethiopia evaluated the influence of areas exclosures on woody species diversity, population structure and regeneration status. A total of 36 and 27 quadrats, each 20 m × 20 m, were used to collect data in exclosures and non-exclosures, respectively. Within quadrats, four 5 m × 5 m and 2 m × 2 m quadrats at the corners were used to sample saplings and seedlings, respectively. In exclosures, 35 woody species representing 21 families and 29 genera were recorded; 19 woody species representing 13 families and 13 genera were recorded in the non-exclosure. *Acacia etbaica* was the most dominant species in the two land-uses. The Shannon diversity index was 1.77 ± 0.46 in exclosures and 1.39 ± 0.46 in non-exclosures. Shannon and Simpson diversity indices showed a significant difference between the two land-uses ($p < 0.01$). The regeneration status of all wood species in exclosures was good, only fair in non-exclosures. Area exclosures have thus played a great role in the restoration of degraded lands by improving vegetation diversity and regeneration status. The least dominant woody species should be maintained through active restoration. Continuous follow-up, maintenance of soil water conservation structure to improve soil fertility will further help enhance the woody species diversity and abundance.

Keywords Restoration · Diversity · Regeneration status · Exclosure

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✉ Mubarek Eshetie
eshete99@gmail.com

Tsegaye Gobezie
tsegaye_gobezie@yahoo.com

Seid Muhie Dawd
seid.muhie@wu.edu.et

1 Sekota Dryland Agricultural Research Center, P.O. Box 62, Sekota, Ethiopia

2 Department of Forestry, College of Agriculture, Wollo University, P.O.Box 1145, Dessie, Ethiopia

Introduction

Land degradation is a widespread serious threat to the livelihoods of 250×10^6 people residing in drylands (Yirdaw et al. 2017), where an estimated 12×10^6 ha are degraded each year (James et al. 2013; Yirdaw et al. 2017). Deforestation in Ethiopia has been a major land degradation problem for the past three millennia with severe ecological and socio-economic consequences (Birhane et al. 2007; Yirdaw et al. 2014).

Several global initiatives have been launched against land degradation, including rehabilitation of degraded drylands (Yirdaw et al. 2017), including many efforts to reverse deforestation and land degradation in Ethiopia (Ubuy et al. 2018). Area exclosure, hereafter "exclosure", is a land management practice whereby livestock and humans are excluded from openly accessing a severely degraded area (Aerts et al. 2009). Exclosures are advantageous over other methods such as hillside terracing and planting; it is fast and inexpensive, relatively easy, requires less investment in planting materials, site preparation and management (Birhane et al. 2017), and existing vegetative material may invade the site faster and with better coverage than planted seedlings. They are implemented for management or research purposes (Ubuy et al. 2014) to improve degraded and generally open-access lands (Birhane et al. 2007; Mekuria 2007) and to prevent agricultural use (Mekuria et al. 2009). Not only do they help restore native woody plants (Aerts et al. 2009; Ubuy et al. 2014), they also help control soil erosion (Mekuria et al. 2009) and improve soil fertility (Mekuria 2013a).

In Ethiopia today, exclosure is one of the most widespread practices for re-greening (Lemenih and Kassa 2014) and restoring secondary forests with assisted natural regeneration. By the end of 2013, exclosures in Ethiopia had been established on 3 million hectares (1.55 million hectares in the Amhara region in northeastern Ethiopia) (Lemenih and Kassa 2014), and are now common in northern Ethiopia to fight land degradation and restore species composition and diversity (Descheemaeker et al. 2006; Yayneshet et al. 2009).

When an exclosure is established to improve the overall ecological condition of an area, the initial woody species diversity needs to be quantified and evaluated to understand the restoration potential of the woody species in the exclosure, and provide a good database to aid the design of management measures in the exclosure (Naidu and Kumar 2016). This information is also used to develop a comprehensive approach to conserve important but less-dominant woody species and enhance the regeneration capacity of dominant woody species to maintain the ecological balance in the exclosure (Naidu and Kumar 2016). The present study compared the effect of exclosure and non-exclosure on woody species restoration, diversity, population structure, and regeneration status at the three sites in northeastern Ethiopia.

Materials and methods

Study area

The study sites in Sekota district, northeastern Amhara, Ethiopia were located at 12°41′N, 12°31′N and 12°42′N/39°01′E for Gateno and Mildam, Jinqaba, respectively. The altitudinal range of the study sitesis about 1340–2220 m a.s.l. (Figure 1). The mean annual temperature ranges from 11.2 to 29.1 °C. The rainfall pattern is unimodal with an annual rainfall of 300–653 mm have been recorded for 23 years (1996–2017) at Aybra Meteorological Station (NMSA

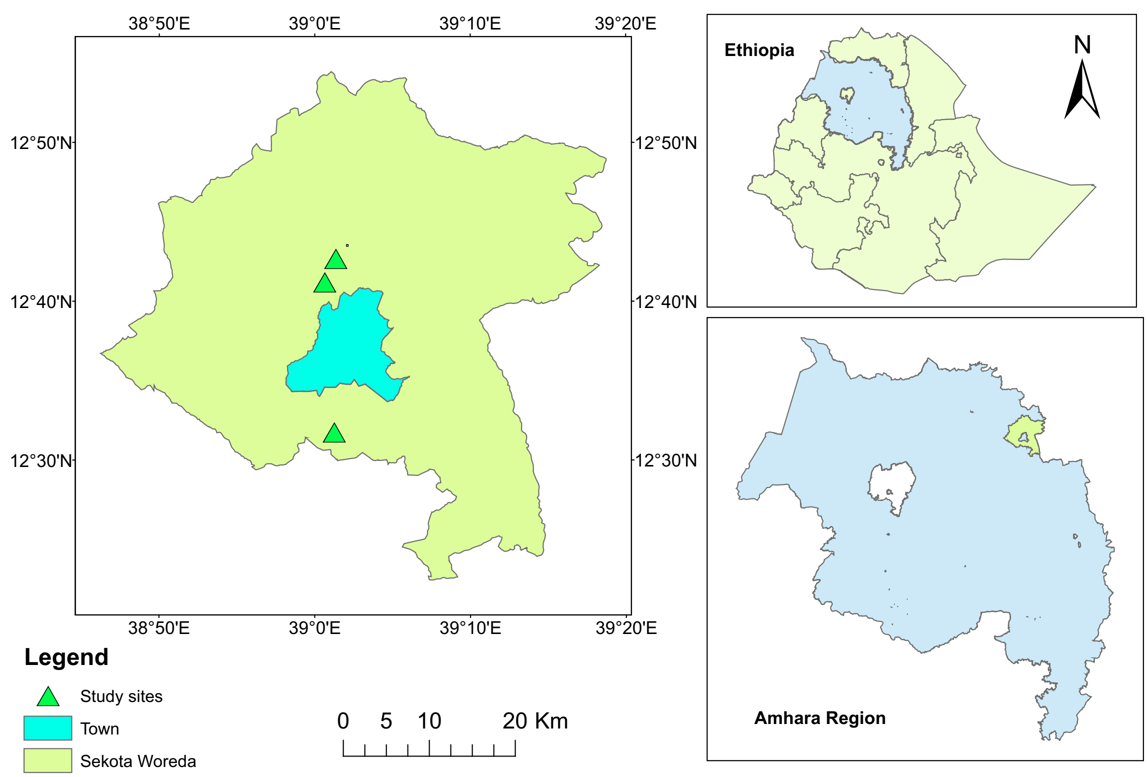

Fig. 1 Map showing the location of the three study sites in Ethiopia

2017). Rainfall is concentrated in between June and August; the other 9 months are considered dry.

The vegetation around the Sekota districts could be categorized as dry evergreen afromontane forest with several dominant species such as *Acacia etbaica*, *Acacia abyssinica*, *Acacia albida*, *Acacia seyal*, *Acacia tortilis*, *Dodonaea angustifolia*, *Erythrina abyssinica*, *Euphorbia candelabrum*, and *Olea africana*. Broad-leaved Fabaceae species dominate in the Sekota districts (Mengistu et al. 2005). The soil in the study sites is generally infertile, coarse-textured, and sandy.

Sampling methods

Three exclosures (Gateno, Mildam, and Jinqaba) were selected based on their comparable management level, soil, climate (Mengistu et al. 2005; Mekuria 2007) and accessibility. All exclosures were 10 years old and were previously open grazing lands. Soil and water conservation structures, such as half-moon, soil and stone bunds had been set up in the exclosures, and free grazing or browsing was not allowed. However, the non-exclosure had no soil or water conservation structures and were open for grazing or browsing. The area coverage of the exclosure was 16.34 ha for Gateno, 15.4 ha for Mildam and 12.2 ha for Jinqaba. In each exclosure, an adjacent non-exclosure (grazing lands) was selected to have paired exclosure and non-exclosure sites to understand how changes in land-use have influenced woody species diversity and abundance (Mekuria et al. 2018).

Quadrats and transect lines were laid with a maximum interval of distance of 100 m and 250 m, respectively, for the two land-uses. Three transect lines were laid in each selected exclosure and non-exclosure sites. The number of quadrats was determined based on vegetation density, spatial heterogeneity of vegetation, and area of the site (Mengistu et al. 2005). The number of quadrats placed was proportional to the area coverage and vegetation density; 15 plots were set up for Gateno, 12 for Mildam and 9 for Jinqaba. A total of 36 and 27 square quadrats were set up in exclosure and non-exclosure, respectively. The initial quadrat in all transects was laid out 50 m from the inside edge of the exclosures and non-exclosures to avoid edge effects; subsequent quadrats were arranged systematically (Mekuria and Aynekulu 2013).

Along each transect, sample quadrats (main quadrats) measuring 20 m × 20 m (400 m^2) were laid out to sample trees (Fig. 2). In each main quadrat, a subplot was placed in each corner, each with a subquadrat of 5 m × 5 m to sample saplings and 2 m × 2 m for seedling (Birhane et al. 2007).

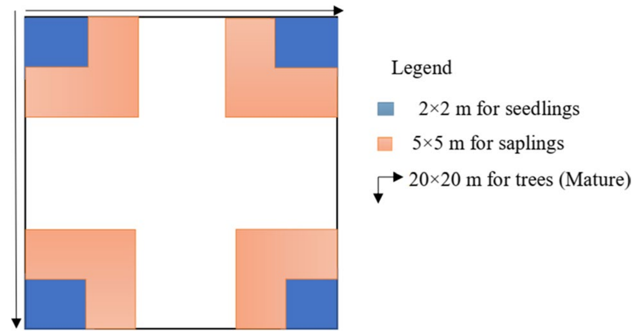

Fig. 2 Diagram of the sampling areas inside each 20 × 20 m main quadrat set up for exclosure and non-exclosure sites

Data collection

The diameter and height of individuals of woody species were measured using a caliper and graduated wooden pole, respectively. The diameter was measured at the soil surface (basal stem diameter), at 0.7 m for saplings and 1.3 m (breast height) for mature trees or shrubs. Individuals were then grouped into height classes < 1.5 m (seedlings), 1.5-3 m (saplings), and > 3 m (trees) and diameter classes of < 2.5 cm (seedlings), 2.5–5 cm (saplings) and > 5 cm (trees). In each plot, all woody species were identified based on published floras for Ethiopia (Edwards et al. 1969, 1995, 1997; Hedberg and Edwards 1989; Hedberg et al. 2003, 2006) and recorded.

Data analyses

Woody species diversity and evenness

Species richness, i.e., the total number of species in a sample area, is very sensitive to the number of individuals (Gotelli and Chao 2013). An increase in species richness does not mean an increase in species diversity. Species richness also does not measure the evenness of the species abundance distribution (Gotelli and Chao 2013). The diversity of woody species was analyzed using the Shannon diversity index (H') (Shannon and Weiner 1963), which gives more weight to rare species, and the Simpson diversity index (D) (Simpson 1949), which gives more weight to the most dominant species in a sample (Magurran 2004). Sorensen's coefficient of similarity was used to compute similarity in the composition of woody species between exclosure and non-exclosure (Kent and Cooker 1992). Non-metric multidimensional scaling (NMDS) based on Bray–Curtis dissimilarity was used to visualize and evaluate patterns of dissimilarity within exclosure and non-exclosure species composition. Permutational multivariate analyses of variance (PERMANOVA) (Anderson 2001) was used to test the differences in species composition between exclosure and non-exclosure.

Structural data analyses

The diameter at breast height and height of the woody plants were used for a horizontal and vertical structure analysis. The stand structure was expressed in terms of species abundance, frequency, density, dominance, and importance value index (IVI). To understand the population structure of woody individuals and some important woody species, we constructed a histogram using the frequency distribution of diameter and height classes of the arbitrary classes (Birhane et al. 2007). The number of seedlings, saplings and mature or adult woody individuals were counted and compared to assess the regeneration potential of exclosures and non-exclosures.

Statistical analyses

The differences between land-use types for each site or differences among sites for each land-use were tested using linear mixed effect models with land-use as the fixed effect and site or replicate plots as random effects. The statistical significance for all the tests was set at $P \leq 0.05$. All analyses were conducted using R version 4.0.2 (R Core Team, R Foundation for Statistical Computing, Vienna, Austria), and Statistical Package for Social Science (SPSS version 22; IBM, Armonk, NY, USA).

Results

Species-accumulation curve for exclosure and non-exclosure

The species-accumulation curve for the exclosure displayed a sharper increase initially to plot 16 and then remained flat into plot 28. After plot 29, the number of species increased until it flattened from plot 33 on. In the non-exclosure, the curve initially rose, then flattened after plot 6. Then, after plot 20 the number of species increased and remains flat. Therefore, the graph showed that sample quadrats were sufficient and could give information about woody species indicators in the two land-uses (Fig. 3).

Species composition and abundance

PERMANOVA results indicated that the species composition significantly differed among the land-uses ($F = 6.37$, $P < 0.001$). *Grewia viscosa*, *Ormocarpumt trachycarpum*, and *A. etbaica* were selected based on their higher regression

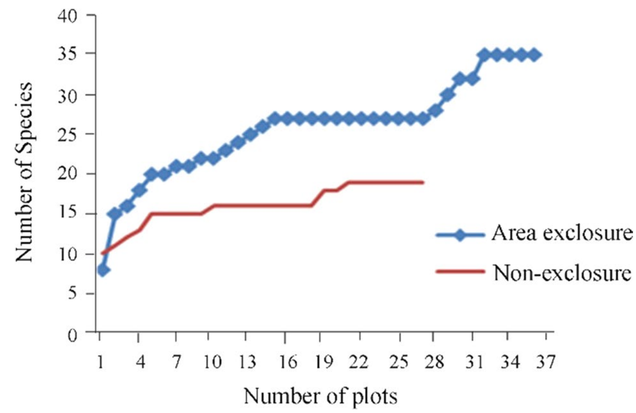

Fig. 3 Species-accumulation curve for the exclosure and non-exclosure

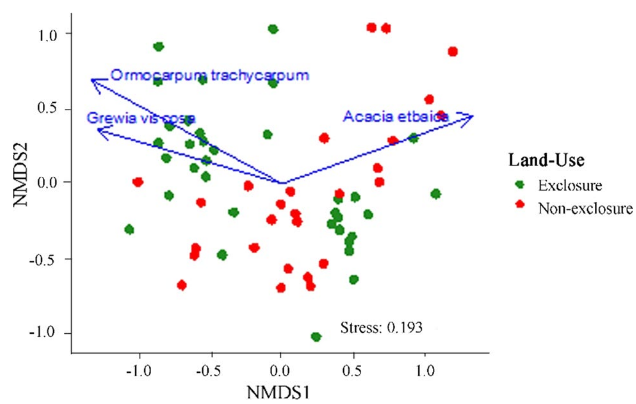

Fig. 4 Nonmetric multidimensional scaling based on Bray–Curtis dissimilarities for exclosure and non-exclosure. Arrows indicate significant correlations and the lengths of arrows are relative to the strength of the correlation

coefficient value. The abundance of *G. viscosa* and *O. trachycarpum* was significantly correlated with exclosure species composition ($P < 0.001$). *Acacia etbaica* was significantly correlated with exclosure and non-exclosure species composition ($P < 0.001$) (Fig. 4).

A total of 36 woody species belonging to 21 families and 29 genera were recorded in exclosure and non-exclosure. In the exclosure, a total of 35 woody species belonging to 21 families and 29 genera were recorded. In the non-exclosure, 19 woody species representing 13 families and 16 genera were recorded. Eighteen woody species were recorded both in exclosure and non-exclosure, while 17 species and 1 species were found only in exclosure and non-exclosure, respectively (Tables S1, S2).

The abundance of woody species range varied from 1 (*Cordia africana* and *Calpurnia aurea*) to 1030 (*A. etbaica*) in the exclosure. In the non-exclosure, abundance ranged from 1 (*E. abyssinica*) to 384 (*A. etbaica*) (Tables S1, S2).

Based on Sorensen's coefficient of similarity index, the similarity of woody species between the exclosure and non-exclosure was 41%.

Density, frequency, basal area and importance value index (IVI)

Stem density, height and basal area of woody species differed significantly between land-uses at each site. Heights at the Gateno exclosure differed significantly from those at the Milldam and the Jinqaba exclosures. However, there were no significant differences in density, frequency and basal area among non-exclosures at the three sites (Table 1). The mean density of woody species varied from 0.75 to 715.25 for exclosure and 1 to 355.5 for non-exclosure at the species level (Tables S1, S2).

In the exclosures, the highest frequency was recorded for *A. etbaica*, followed by *Rhus vulgaris* and *Euclea racemosa* subsp. schimperi. *Calpurnia aurea*, *Cordia africana*, and *Grewia bicolor* occurred in only one plot, and its frequency was lower (2.78%) (Tables S1, S2). In the non-exclosures, *A. etbaica*, *Cassia didymobotrya*, and *R. vulgaris* occurred frequently and *E. abyssinica*, *Combretum molle*, and *Dichrostachys cinerea* less frequently.

Acacia etbaica, *Euclea racemosa* subsp. schimperi, and *Opuntia ficus indica* scored high for basal area (m^2/ha) in exclosures, and *G. bicolor*, *C. aurea*, and *C. africana* had lower basal area (Tables S1, S2). In non-exclosures, *A. etbaica*, *Euphorbia candelabrum*, and *A. tortilis* had higher basal area, and *Ormocarpum trachycarpum*, *D. cinerea*, and *Stereospermum kunthianum* had lower basal area.

Importance value index indicated that, *A. etbaica*, *E. racemosa* subsp. schimperi, *D. angustifolia*, and *R. vulgaris* were the most dominant woody species and *Buddleja polystachya*, *G. bicolor*, *C. aurea*, and *C. africana* the least dominant species in the exclosures (Table S1). In the non-exclosures, *A. etbaica*, *E. candelabrum*, *R. vulgaris*, and *C. didymobotrya* were the most dominant woody species and *C. molle*, *D. cinerea*, *E. abyssinica*, and *S. kunthianum* the least dominant (Table S2).

Richness, evenness and diversity of woody species

Shannon and Simpson diversity indices and richness of woody species differed significantly between the two land-uses at each site. However, Shannon evenness did not differ significantly between the two land-uses. Shannon and Simpson diversity and species richness at Gateno (exclosure and non-exclosure) differed significantly between the Milldam and the Jinqaba sites (exclosures and non-exclosures) (Table 2).

Horizontal and vertical structure and regeneration status

In the exclosures, the horizontal structure of *A. etbaica*, *D. angustifolia*, and *R. vulgaris* had an inverted J-shape, and *E. racemosa* subsp. schimperi had a bell shape. In the non-exclosure, *E. racemosa* subsp. schimperi and *R. vulgaris*, and *D. angustifolia* had a bell shape and irregular shape, respectively (Figs. S1, 2). In addition, seedlings (45%) were more numerous than saplings (43%) and trees (12%) in the exclosures. More saplings (49%) than seedlings (39%) and trees (12%) were found in the non-exclosures (Fig. S3).

Table 1 Mean (± standard deviation) density, height and basal area of woody species from exclosures and non-exclosures within each site

Land-use/site	No. of species	Density (Individuals/ha)	Height (m)	Basal area (m^2/ha)
Gateno				
Exclosure	9	161.12 ± 45.24^{Aa}	1.93 ± 0.29^{Ab}	0.037 ± 0.013^{Aa}
Non-exclosure	5	105.89 ± 40.23^{Ba}	2.06 ± 0.37^{Ba}	0.030 ± 0.014^{Ba}
Mildam				
Exclosure	17	142.73 ± 52.34^{Aa}	2.41 ± 0.49^{Aa}	0.040 ± 0.007^{Aa}
Non-exclosure	10	73.14 ± 23.93^{Ba}	2.07 ± 0.40^{Ba}	0.032 ± 0.012^{Ba}
Jinqaba				
Exclosure	17	168.52 ± 59.58^{Aa}	2.36 ± 0.29^{Aa}	0.066 ± 0.062^{Aa}
Non-exclosure	12	89.82 ± 39.06^{Ba}	1.67 ± 0.24^{Ba}	0.036 ± 0.017^{Ba}
Total				
Exclosure	35	156.84 ± 51.01^{A}	2.20 ± 0.42^{A}	0.045 ± 0.033^{A}
Non-exclosure	19	89.62 ± 36.46^{B}	1.94 ± 0.37^{B}	0.033 ± 0.014^{B}

Notes Means followed by different capital letters indicate significant differences between land-use within each site; different lowercase letters indicate significant differences among the three sites within a land-use type (linear mixed effect models with Tukey's HSD at $P \leq 0.05$)

Table 2 Mean (±standard deviation) diversity, richness and evenness of woody species from exclosure and non-exclosure within each site

Land use/site	Shannon (H')	Simpson (1/D)	Evenness	Richness
Gateno				
Exclosure	1.41 ± 0.44^{Ab}	3.55 ± 1.40^{Ab}	0.72 ± 0.18^{Ab}	6.87 ± 1.60^{Ab}
Non-exclosure	0.73 ± 0.45^{Bb}	1.51 ± 0.44^{Bb}	0.59 ± 0.21^{Bb}	$2.89 \pm 0.1.27^{Bb}$
Mildam				
Exclosure	1.95 ± 0.21^{Aa}	5.3 ± 1.11^{Aa}	0.80 ± 0.04^{Aab}	11.67 ± 2.96^{Aa}
Non-exclosure	1.82 ± 0.23^{Ba}	5.48 ± 1.37^{Ba}	0.90 ± 0.06^{Aa}	7.55 ± 1.74^{Ba}
Jinqaba				
Exclosure	2.11 ± 0.33^{Aa}	6.78 ± 2.03^{Aa}	0.85 ± 0.05^{Aa}	12.67 ± 3.77^{Aa}
Non-exclosure	1.61 ± 0.25^{Ba}	4.47 ± 1.34^{Ba}	0.83 ± 0.06^{Aa}	7.22 ± 2.04^{Ba}
Total				
Exclosure	1.77 ± 0.46^{A}	4.94 ± 1.96^{A}	0.78 ± 0.18^{A}	9.94 ± 3.8^{A}
Non-exclosure	1.39 ± 0.59^{B}	3.82 ± 2.07^{B}	$0.77 \pm 0.19^{A0.77}$	5.96 ± 2.71^{B}

Notes Means followed by different capital letters indicate significant differences between land-use within each site; different lowercase letters indicate significant differences among the three sites within a land-use type (linear mixed effect models with Tukey's HSD at $P \le 0.05$)

Discussion

Woody species composition and abundance

The results revealed that the composition and abundance of woody species in the exclosures were higher than in the non-exclosures. In the exclosures, soil and water conservation structure, protection from illegal wood cutting, excluded from the animal intervention (trumping and overgrazing) have applied properly. This management could be contributing to increasing woody species composition and abundance and as well as may allowed rise seed bank in exclosure. Similarly, 38 woody species representing 17 families were found in 10-year exclosure in semiarid part of northern Ethiopia (Gebregerges et al. 2018). According to Teketay et al. (2018), the continuous anthropogenic disturbances (cutting of trees for fuelwood, construction, and annual human-induced fires), heavy browsing, and overgrazing have a great contribution to decreasing of woody species composition in non-exclosures. This idea agrees with other findings from northern Ethiopia (Yayneshet et al. 2009; Mekuria 2013b; Gebrehiwot and Veen 2014), southern Ethiopia (Rift Valley) (Mohammed et al. 2015), northwestern Ethiopia (Mekuria et al. 2018).

Density, frequency, basal area, and importance value index

Acacia etbaica has higher density, frequency, and thus is the most dominant species in the two land-uses. In the study districts, this species is present in all land-uses (farmlands, around roads and homes, steep hills, and valleys). In the study exclosures, *Euclea racemosa* subsp. schimperi, *D. angustifolia*, and *Rhus vulgaris* were also frequently observed. *Dodone angustifolia* and *A. etbaica* in particular serve a pioneer species that start to germinate after exclosure. *Acacia etbaica* is a known pioneer species and more dominant in disturbed sites, taking advantage of primary succession (Birhane et al. 2006).

Cordia africana, *Calpurnia aurea*, and *Grewia bicolor* were present at lower density and frequency in exclosures than in non-exclosures. *Cassia didymobotrya* and *E. racemosa* subsp. *schimperi* were observed frequently in non-exclosures. The reason these species have higher density in non-exclosures is because they are unpalatable to livestock. According to Tessema et al. (2011) heavy grazing/browsing might reduce plant species density over time.

Basal area in the exclosures was higher than in the non-exclosures at each site. The difference in basal area between the exclosures and non-exclosures could be due to the high abundance of woody species in the exclosures. The greater difference in basal area between exclosures and non-exclosures could be due to the high number of multi-stemmed trees in the exclosures, leading to bigger diameters (Birhane et al. 2007).

Acacia etbaica, *E. racemosa* subsp. schimperi, *D. angustifolia*, and *R. vulgaris* are the most dominant woody species in the exclosures; *A. etbaica, Euphorbia candelabrum, C. didymobotrya, and R. vulgaris* are the most dominant species in the non-exclosures. The high basal area of *A. etbaica* and *Euclea racemosa* subsp. *schimperi* contributed to the higher IVI in the exclosures. However, the IVI of *D. angustifolia* increased due to an individual's density. On the other hand, the higher IVI of *Euphorbia candelabrum* was due to its large diameter. Similarly, Menigstu et al. (2005) and Birhane et al. (2006) reported that *A. etbaica* is a dominant woody species in northern Ethiopia.

The IVI is also used for prioritizing species conservation; species with a low IVI need high conservation priority compared to ones with high IVI (Zegeye et al. 2006). Over

28% of the IVI was recorded by *A. etbaica*, while most of the other woody species had lower IVI except some other dominant species. According to Kacholi (2014), the presence of many species with lower IVI values is an indication that the majority of species are rare. Schwarz et al. (2003) also suggested that the rarity of species may be due to such factors as a resource gradient, poor dispersal, and natural disturbances.

Dichrostachys cinerea, *Combretum molle*, and *S. kunthianum* were the least dominant species in the non-exclosures. Because the first two species are used for local construction and fencing materials, fuelwood, and animal forage and many parts of *C. molle* are used for medicinal and other purposes, they likely are more heavily used than the other woody species by humans or animals. In fact, studies in northern Ethiopia indicated that anthropogenic and animal impacts during maturity or early regeneration could be a sign of increased vulnerability of the plant species in non-exclosures (Yayneshet, et al. 2009; Gebrehiwot and Anne, 2014; Atsbha et al. 2019).

Richness, evenness and diversity

The richness and Shannon and Simpson diversity indices of woody species were higher in the exclosures than non-exclosures at each site, as did other studies in northern Ethiopia (Yayneshet et al. 2009; Mekuria and Aynekulu 2013; Mekuria 2013a, b) and in a 10-year exclosure compared with a non-exclosure in semi-arid northern Ethiopia (Gebregerges et al. 2018). However, the Shannon evenness was relatively similar for the two land-uses, indicating a balanced distribution of the individuals of woody species in the two land-uses.

Stand structure and regeneration status

Diameter at breast height (DBH) and height distribution in arbitrary classes can help determine the regeneration status of woody species (Senbeta and Teketay 2001). Different patterns of species population structure can indicate variation in population dynamics (Feyissa et al. 2013). Senbeta et al. (2014) categorized the regeneration status as 1, good regeneration, if numbers are in the order seedlings > saplings > adults; 2, fair regeneration, if seedlings > or < saplings > or < adults; 3, poor regeneration, if the species survives only to the sapling stage or only the seedling stage (seedlings and saplings may number fewer, more or equal to the number of adults); 4, no regeneration, if a species is present only in adult form; 5, reappearing, if the species has no adults, only seedlings or saplings.

Accordingly, in the exclosures, the horizontal structure of *A. etbaica*, *D. angustifolia*, *R. vulgaris*, and all wood species had an inverse J-shape, indicating that woody species have good regeneration status in exclosures. However, *E. racemosa* subsp. *schimperi* has a bell-shaped population structure; thus, the intermediate-sized individuals were more numerous than seedlings and trees because this species could be more affected by natural disturbances than other woody species.

In the non-exclosures, woody species population structures were as inverted J-shape, bell shape, or irregular shape. *A. etbaica* with its inverted J-shaped distribution has a good regeneration status. The high number of individuals in the lower diameter classes and decreasing numbers of individuals in the higher diameter classes in northern Ethiopia was reported previously (Mengistu et al. 2005; Birhane et al. 2006; Birhane et al. 2007).

Euclea racemosa subsp. *schimperi* and *R. vulgaris* had bell-shaped curves and thus, a fair regeneration status more individuals in the middle class. *Dodonea angustifolia* with its irregular-shaped curve, had fewer individuals in class 1, more in the class 2, then also fewer in class 3. This species might be palatable to animals, and thus browse, graze or trample small-diameter individuals.

The vertical structure of some dominant species like *A. etbaica*, *E. racemosa* subsp. schimperi, and *R. vulgaris* in exclosures was grouped as having good regeneration and in non-exclosures as fair regeneration. In general, the horizontal and vertical regeneration status could not describe the regeneration potential of the species separately. Therefore, the regeneration status of all woody species could be described in terms of both horizontal and vertical structures. The regeneration status can be influenced by selective removal of small diameter class individuals and human disturbance, livestock trampling, or browsing, and other biotic and biotic factors in the non-exclosures, which might retard normal recruitment (Adamu et al. 2012; Teshager et al. 2018).

Conclusion

We determined woody species diversity, composition and abundance, population structure, and regeneration status in exclosures and non-exclosures at three sites. Exclosures had more woody species diversity, composition, and good regeneration status. In exclosures, land management and protection from human intervention could improve soil moisture and fertility, which consequently increase the woody species composition, abundance, diversity, and regeneration potential. The regeneration status of all woody species in the non-exclosures was categorized as fair which could be because the dominant woody species such as *A. etbaica* have coppicing potential after browsing and trampling.

In general, exclosures played a great role in the restoration of degraded lands by improving the vegetation diversity and regeneration status. The least-dominant important woody species should be maintained through active restoration rather than left to passive restoration. Future research should be carried out on the composition of non-woody species in these areas and on the ecosystem service value of exclosures. Interaction between local people and exclosure management should also be studied in depth.

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