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Research Article

Area exclosure with moisture harvesting structures relative to only exclosure facilitates the restoration of woody plants in a degraded area in Alaba Kulito, Southern Ethiopia

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Abstract

The study aimed to evaluate the effect of area exclosure established in a degraded area with moisture harvesting structures (EX-SWC) relative to the adjacent exclosure area without moisture harvesting structures (EX) in restoring the woody plants. Vegetation data from a total of 30 plots that has an area of 20 m x 20 m, in the EX-SWC and the adjacent EX area were collected, independently. The density of trees and seedlings, diversity, vegetation structure and Importance Value Index (IVI) were analysed. Pearson's correlation was also used for the data analysis. The Shannon diversity index was 1.6 and 1.57 in the EX-SWC and EX area, respectively. The relative density of trees (578 stems/ha) and seedlings (1530 stems/ha) in the EX-SWC area were relatively higher than the relative density of trees (466 stems/ha) and seedlings (1202 stems/ha) in the adjacent EX area. There was no significant relationship between the number of moisture harvesting structures established in each plot and the relative density of seedlings per plot ($p < 0.05$, R^2 0.18). The relative density of seedlings at the lower height classes (1-60 cm) in the EX-SWC area was relatively higher than the adjacent EX area. The IVI result for most of the recorded species in the EX-SWC area was also relatively higher than in the EX area. The overall results showed that the implemented moisture harvesting structures facilitated the regeneration of woody plants in the degraded area. Therefore, we recommend implementing soil and water conservation structures in degraded area restoration projects to facilitate the regeneration of woody plants.

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Introduction

The major causes of land degradation are related to human activities such as deforestation, shifting cultivation, overgrazing, steep slope farming, overuse of chemical fertilizers, forest resources depletion, etc. (Acharya and Kafle, 2009). Land degradation decreases land's biological productivity and its usefulness to humans by causing a reduction of the capacity of land resources to perform essential functions (Johnsen and Lewis, 2007; Hurni et al., 2010). Land degradation also has an effect on the development efforts and it decreases agricultural productivity and ecosystem services and it also has an effect on the type of plants grown in the area, availability of water, and caused loss of biodiversity (Mekonnen, 2013; Mebrat, 2015). To reduce the effect of land degradation problems different measures to reduce its impact have to be undertaken. The major principles applied for reducing land degradation problems are maximizing vegetation cover to prevent erosion, replacing nutrients removed using different mechanisms, and putting physical conservation structures such as terraces, contour bunds, vegetation strips etc. (Yirdaw et al., 2017; Siyum et al., 2019).

Area exclosure, which is done by closing off areas from interference and damage by both humans and animals, is one of the techniques applied for the restoration of degraded areas. Area exclosure, a major rehabilitation technique is commonly used for the restoration of vegetation and soil in degraded lands (Mengistu et al., 2005; Mekuria et al., 2007; Mekuria and Ayenekulu, 2011; Mekuria and Yami, 2013). Studies showed that exclosure is known to improve ground vegetation cover, which later enhances better soil conditions, microclimate conditions and water percolation (Tefera et al., 2005; Birhane et al., 2006; Yosef, 2015).

Most commonly, two types of area exclosures are applied in the restoration of degraded land vegetation and these are (1) only closing off the degraded area from interferences of human interventions (leaving it to natural regeneration), and (2) Closing off degraded land while simultaneously implementing additional measures such as establishing water harvesting structures to enhance and speed up the regeneration process. For the facilitation of natural regeneration in degraded lands, instead of applying only area exclosure, establishing moisture harvesting structures is recommended with the assumption of improving the soil water and soil nutrients (Jia et al., 2006; Vohland and Barry, 2009; Gammoh, 2011).

Derib et al. (2009) indicated that moisture harvesting structures improve moisture in the root zone of plants and also it can reduce sediment load and erosion at downstream sites in exclosure areas. Moisture and nutrients are basic resources for the growth and productivity of trees and conservation of moisture help in improving the growth and productivity of trees (Sumbali et al., 2012; Yitbarek et al., 2012).

Different studies on the impacts of exclosures that does not have moisture harvesting structures (EX) relative to their adjacent grazing lands on the regeneration of woody plants are available; and their results showed that exclosures improved soil organic matter content, biomass production, diversity and density of woody plants as compared to their adjacent open grazing areas (Birhane et al., 2006; Mekuria et al., 2007; Veldkamp et al., 2011; Getseselassie, 2012; Mekuria and Yami, 2013; Teketay et al., 2018; Gebregergs et al., 2019; Alem et al., 2020). Knowledge on the effects of area exclosure with moisture harvesting structures (EX-SWC) relative to area exclousre without moisture harvesting structures in restoring woody plants are lacking. Therefore, the objective of this study was to evaluate the impact of EX-SWC relative to the adjacent EX area in facilitating the regeneration of woody plants in a degraded area. It was hypothesized that the EX-SWC area facilitated the regeneration and diversity of woody plants in a degraded area relative to the adjacent EX area.

Materials and Methods

Description of the study area

The study was carried out in Habibo Furana Kebele, in Alaba Kulito special wereda, located about 310 km away from Addis Abeba, in the Southern Nations, Nationalities, Peoples', Region (SNNPR). Geographically, it is located at 07° 22′ 37" N and 03° 80′ 75" N. The altitude of the area is 1877 meters above sea level (m.a.s.l.). According to the data collected during the study, the slope of the area ranges from 5-20%. The rainfall and temperature of the area based on the analysis of the climatic data (1997-2017) collected from metrological stations in Alaba town located 5 Kilometres away from the study area is presented in Figure 1. The mean minimum and maximum annual temperature of the study area are 14.3 °C and 28.5 °C, correspondingly. The highest temperature occurs in March (31.3 °C) while the lowest temperature is recorded in November (2.5 °C). The mean annual rainfall of the area is 1041.9 mm. The area receives bimodal rainfall (Figure 1). As a result of illegal cutting of trees by the local community and over grazing problems, the study area was once degraded. To restore the woody plants in the degraded land, area exclosure for rehabilitation with moisture harvesting structures in part of the area and only area exclosure was implemented in the area. The different moisture harvesting structures implemented in the degraded land in the year 2007 were micro basins, stone bunds, soil bunds and trenches (Figure 2).

Sampling design and data collection

Sampling design

The data for the study was collected after five years of the exclosure interventions for restoration were implemented. In total, 30 major sample plots were considered for the data collection. Out of these total sample plots 15 sample plots were established in the EX-SWC area while the remaining 15 sample plots were laid in the adjacent EX area. The number of plots in the EX-SWC and EX was limited to 15, because of the smaller area size of the EX-SWC area and the adjacent EX area. Each of the sample plots used for the data collection has an area size of 20 m x 20 m (400 m^2). The plots are laid out following a gradient in a line transect.

Vegetation data collection

In each of the sample plots used for the data collection, the woody plant species were identified, and then their diameters at breast height (DBH) was measured using a calliper.

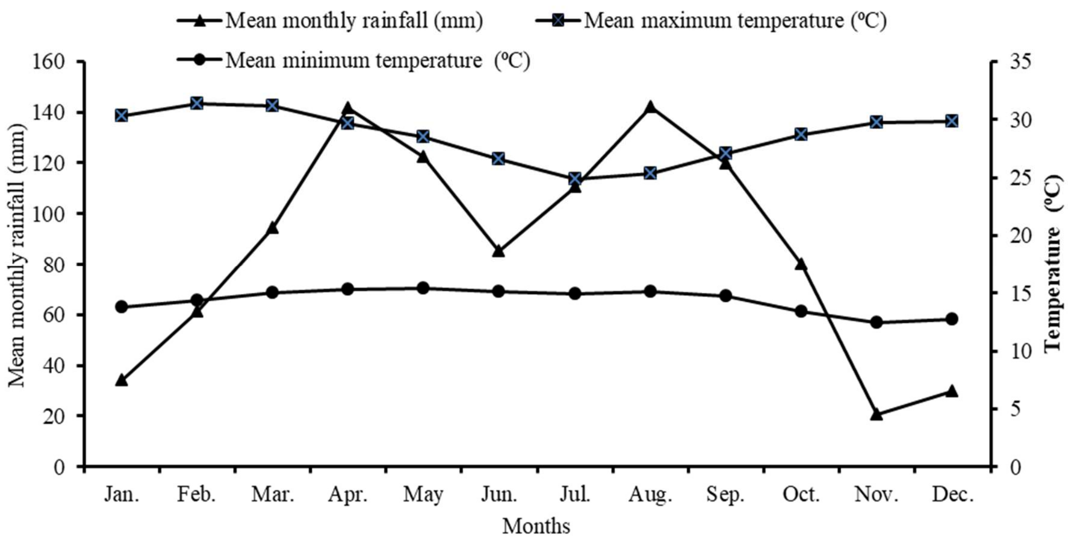

Figure 1. Mean minimum and maximum temperature (°C) and annual rainfall of the study area according to the data from the year 1997-2017.

Figure 2. Stone bunds constructed in the Exclosure area

The height of the trees was measured using a long-ranging rod that was divided and marked in meters. Seedlings (height <70 cm) and saplings (71-113 cm) data of woody species were collected in the whole area of the data collection sample plot. In each of the sample plots, used for data collection, the number and types of the different moisture harvesting structures established were counted and recorded in a data collection sheet. Around the moisture harvesting structures (with in 1 meter distance from the center of the conservation structures), seedlings data were collected. Species identification was done using expert knowledge and field guide manuals (Fichtle and Admasu, 1994; Bekele, 2007). For specimens being difficult to identify in the field, local names of the species (in the Alabigna language) was used.

Data analyses

The Shannon-Wiener Diversity Index (H') was used to determine the diversity of species in both the EX-SWC and the adjacent EX area (1).

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

Where S is the number of species, p_i, the proportion of the individual species to the total, n_i / N.

The equitability (evenness) of species in the EX-SWC area and the adjacent EX area was calculated using H'/H'_{max}, where H'_{max} is ln (natural logarithm) of S (number of species). Vegetation data collected from each plot of the EX-SWC area and the adjacent EX area were used for structural analysis. The seedling data were also analyzed in a hectare base. Correlation analysis was applied to evaluate the association between the numbers of established moisture harvesting structures in a plot with the density of recruited seedlings in each of the respective plots. The similarity index of regenerated native woody species between the EX-SWC area and EX area was analyzed using the Jaccard index (2).

$$SJ = c/(a + b + c) \ldots\ldots(2)$$

Where SJ is the similarity index, c is the number of shared species between the EX-SWC area and EX area and a and b are the number of species unique to the EX-SWC area and EX area.

The Importance Value Index (IVI) was calculated for dominant species. The formulae used to calculate density, frequency and dominance for each of the species (Kent and Coker, 1994) were as follows:

The density of a species = number of plants of a certain species/area.
Relative density = density of a species/total density of all species x 100.
Frequency = number of quadrants of occurrence of a species/total quadrants sampled
Relative frequency = frequency of a species/total frequency of all species x 100.
Dominance = basal area of a species/total area sampled.
Relative dominance = basal area of a species/basal area of all the species x 100.

The basal area was calculated for all species from diameter at breast height using the formula BA = II (DBH/2) ^{2}

Results

Floristic composition and diversity of species

The lists of identified woody plant species in both the EX-SWC and the adjacent EX area, along with their respective densities per hectare is presented in Table 1. In total, 25 woody plant species of trees and shrubs representing 12 families were determined in both the EX-SWC and the adjacent EX area. Out of these identified species, 10 and 2 species belonged to the Fabaceae and Apocynaceae families, respectively. While the rest of the families such as Boraginaceae, Celastraceae, Euphorbiaceae, Lamiaceae, Malvaceae, Oleaceae, Sapindaceae, Solanaceae and Zygophyllaceae were represented by a single species. Out of the total identified woody plant species 6 of them were recorded only in the EX-SWC area while 5 woody plant species were recorded only in the adjacent EX area. Jaccard's index result showed that 65% of the woody species recorded in the EX-SWC area and the adjacent EX area are similar. The diversity (H') of woody plant species in the EX-SWC area (1.6) was relatively greater than in the adjacent EX area (1.57). The species distribution (S') in the EX-SWC area (0.6) was relatively greater than in the adjacent EX area (0.56).

Vegetation structure and density of species

The result on the relative density of trees/shrubs and seedlings in the area where different restoration approaches (EX-SWC and EX) were implemented is presented in Table 1. The density of trees in the EX area (466 stems/ha) was relatively less than the adjacent EX-SWC area (578 stems/ha). The density of seedlings/ha in the EX area (1202 stems/ha) was also relatively lower than the adjacent EX-SWC area (1530 stems/ha).

The relative density of seedlings recorded in the peripheries (within 1-meter distance) of the moisture harvesting structures is presented in Figure 3. The analysis result revealed no significant relationship (R^2=0.18) between the number of moisture harvesting structures established in each plot and the relative density of seedlings/plot (Figure 4). The relative density of trees (stems/ha) in the EX-SWC area was relatively greater than the adjacent EX area for the species of *V. etbaica*, *V. oerfota*, *V. seyal*, *V. tortilis*, *B. aegyptiaca* and *O. africana*. For the species of *V. lahai*, *D. angustifolia* and Gofero (local name of the species) their relative density (stems/ha) in the EX area was relatively greater than in their respective adjacent EX-SWC area. For the species of *V. nigra*, *V. seyal*, *V. tortilis*, *Balanites egyptica*, Gofera and *Olea africana* the relative density of seedlings (stems/ ha) in the EX-SWC area was relatively greater than in the adjacent EX area (Table 1). For *D. angustifolia* and *V. lahai* species, the relative density of seedlings (stems/ ha) in the EX area was relatively greater than in the adjacent EX-SWC area. The relative density of trees in the different diameter class distributions in both of the EX-SWC area and the adjacent EX area is presented in Figure 5. The results indicated that the relative density of tree stems in the diameter classes of 1-5 cm, 5.1-10 cm, 15.1-15 cm and 25.1-30 cm in the EX-SWC area was relatively greater than in the EX area (Figure 5). However, the relative density of trees in the EX area in the diameter classes of 15.1-20 cm, 20.1-25 cm, 30.1-35 cm, 35.1-40 cm, 40.1-45 cm were relatively greater than in the adjacent EX-SWC area (Figure 5). The result on the relative density of tree stems in the different height classes in the EX-SWC area and the EX area is presented in Figure 6. The results indicated that the relative density of trees in the height class of 1-2 meters, 3.1-4 meters, and 6.1-7 meters in the EX-SWC area was relatively greater than in the adjacent EX area. Whereas, the relative density of tree stems in the height classes of 5.1-6 meters and 7.1-8 meters in the EX area was relatively greater than in the adjacent EX-SWC area.

Table 1. List of the woody species recorded in the area exclosure with moisture harvesting structures (EX-SWC) and the adjacent exclosure area without moisture harvesting structures (EX).

No.	Species	Family	EX-SWC area		EX area	
			Density of trees/ha	Density of seedlings/ha	Density of trees/ha	Density of seedlings/ha
1	*Acokanthera schimperi* (A. DC.) Schweinf.	Apocynaceae	2	5		
2	*Balanites aegyptiaca* (L.) Delile	Zygophyllaceae	42	57	4	4
3	*Calpurnia aurea* (Lam.) Benth.	Fabaceae		3	2	5
4	*Carissa spinarum* L.	Apocynaceae		2		
5	*Cordia africana* Lam.	Boraginaceae		2		
6	*Croton macrostachyus* Hochst. ex Delile	Euphorbiaceae	2	3	2	
7	*Dodonaea angustifolia* L.f.	Sapindaceae	15	127	20	543
8	*Entada abyssinica* A.Rich.	Fabaceae	2	3		
9	*Grewia ferruginea* Hochst. ex A.Rich.	Malvaceae	7	8		7
10	*Maytenus gracilipes (loes.) Sebsebe*	Celastraceae	2	2		
11	*Ocimum lamiifolium* Hochst. ex Benth	Lamiaceae			2	
12	*Olea africana* Mill.	Oleaceae	12	7	9	5
13	*Pterolobium stellatum* (Forsk.) Chiov.	Fabaceae	2	3		
14	*Solanum nigrum* L.	Solanaceae.		10		
15	*Vachellia etbaica* Schweinf.	Fabaceae	297	802	254	345
16	*Vachellia nilotica* (L.) P.J.H. Hurter & Mabb.	Fabaceae	5			
17	*Vachellia lahai* Benth.	Fabaceae	3	7	7	11
18	*Vachellia* oerfota (Forssk.) Schweinf.	Fabaceae	30	57	2	
19	*Vachellia senegal* (L.) Willd.	Fabaceae			4	
20	*Vachellia seyal* (Delile) P.J.H. Hurter	Fabaceae	88	110	86	64
21	*Vachellia tortilis* (Forssk.) Galasso & Banfi	Fabaceae	58	308	48	193
22	*Vernonia thomsoniana* Oliv. & Hiern ex Oliv. & Hiern	Asteraceae				2
23	*Gofero**		13	15	23	18
24	*Nekor**				2	4
25	*Tsechie**				4	2
	Total		578	1530	466	1202

*Local names of a species.

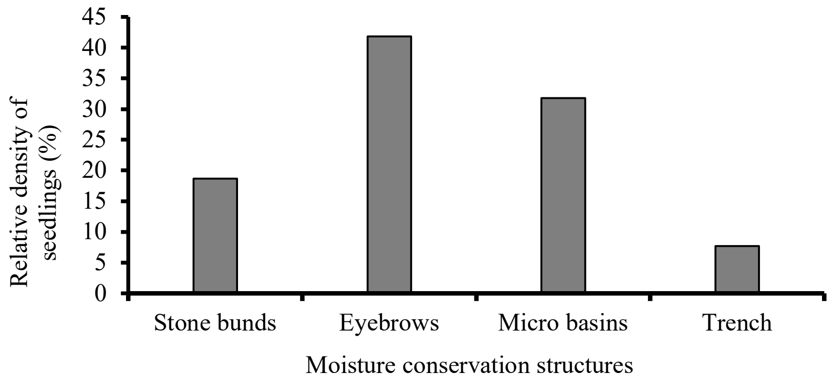

Figure 3. The relative density of seedlings in the peripheries within the 1-meter distance from the moisture harvesting structures.

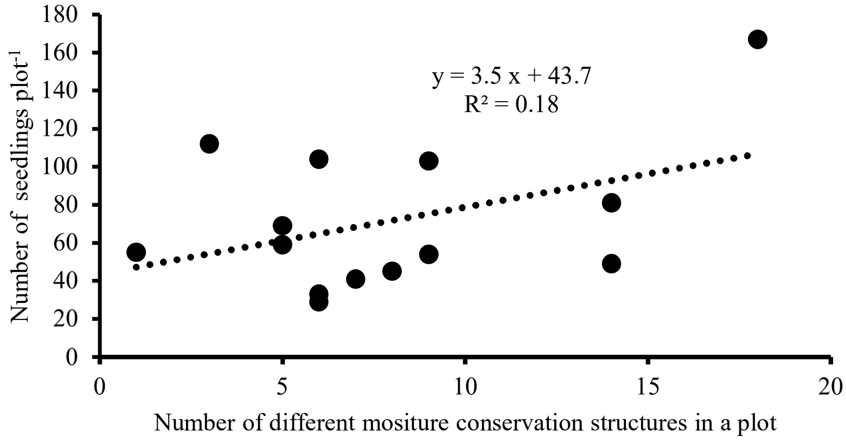

Figure 4. A graph that shows the correlation between the number of moisture harvesting structures/plot and the number of seedlings/plot.

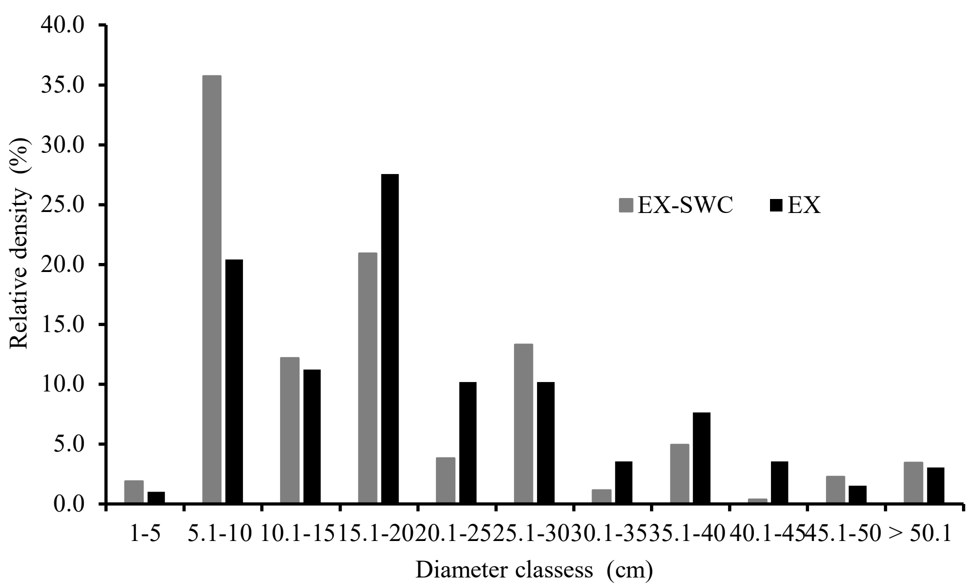

Figure 5. The diameter class distribution of the woody plant species in the exclosure area with soil and water conservation structures (EX-SWC) and exclosure area without soil and water conservation structures (EX).

The height class distribution of the seedlings and saplings in both the EX-SWC area and the adjacent EX area is presented in Figure 7. The results showed that the relative density of seedlings in the height classes of 1-15 cm in the EX area was relatively greater than the relative density of seedlings in the adjacent EX-SWC area. However, in the rest of the seedling height classes (15.1-30 cm, 30.1-45 cm, and 41.1-60 cm) the relative density of seedlings in the EX-SWC area was relatively greater than the adjacent EX area. Besides, the number of recorded species in the different height classes of the seedlings in the EX-SWC area was relatively greater than the number of species recorded in the adjacent EX area at the different height classes of the seedlings.

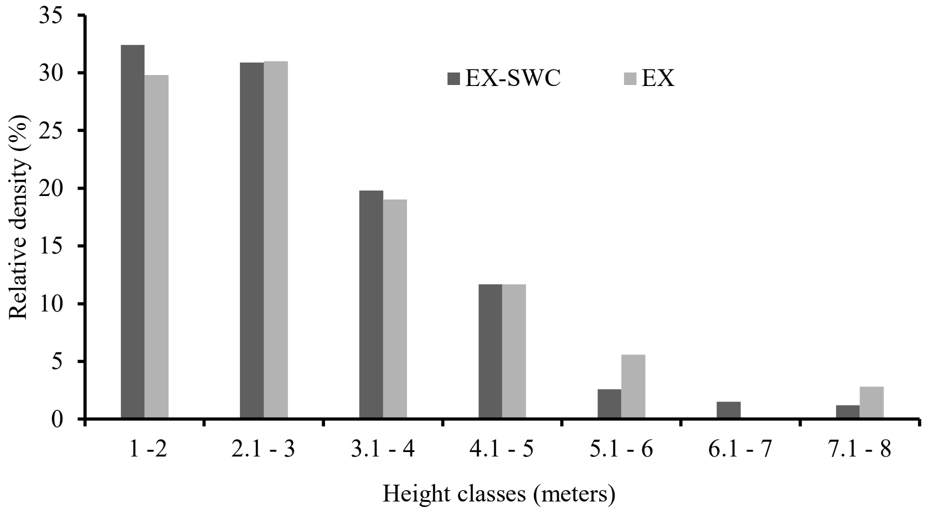

Figure 6. Height class distribution of the woody plants that were measured in the exclosure area with soil and water conservation structures (EX-SWC) and in the adjacent exclosure area without soil and water conservation structures (EX).

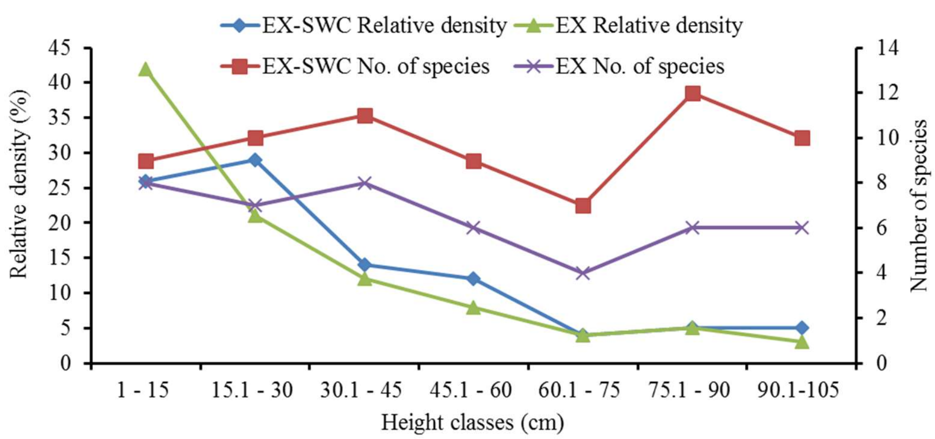

Figure 7. Height class distribution of seedlings and saplings along with the number of recorded species in the exclosure area with soil and water conservation structures (EX-SWC) and the exclosure area without soil and water conservation structures (EX).

Importance value index

The importance value index (IVI) result for the different woody plant species that were recorded in the EX-SWC and EX area is presented in Table 2. The IVI value for the dominant species in the EX area ranged from 5.5-111.1 while it ranged from 1.8-140.2 in the EX-SWC area. The IVI value for the species of *B. egyptica*, *C. macrosytechus*, *G. ferruginea* , *V. etbaica*, *V. oerfota*, *V. sayal*, and *V. tortolis* in the EX-SWC area was relatively greater than in their adjacent EX area. For the species of *D. angustifolia* ,*O. africana, V. lahai* and Gofero their IVI values in the EX area were relatively greater than in the adjacent EX-SWC area. This shows that many of the common species have good distribution in the EX-SWC area than in the EX area In both the EX area and the EX-SWC area, it is observed that the IVI value of *V. etbaica* is highest relative to the other species which could show the better distribution of the species in the EX-SWC area and the adjacent EX area.

Table 2. Importance Value Index (IVI) for the different tree species in the exclosure area with moisture harvesting structures (EX-SWC) and the exclosure area without moisture harvesting structures (EX).

No	Species	Relative density		Relative frequency		Relative dominance		IVI		Rank	
		EX	EX-SWC	EX	EX-SWC	EX	EX-SWC	EX	EX-SWC	EX	EX-SWC
1	*B. egyptica*	0.48	4.76	3.90	8.33	0.02	8.64	4.40	21.74	9	4
2	*C. macrosytechus*	0.26	0.24	1.30	2.38	1.20	0.17	2.76	2.79	10	12
3	*D. angustifolia*	33.75	6.83	15.58	13.10	0.38	0.07	49.72	19.99	2	5
4	*E. abyssinica*		0.24		2.38		0.26		2.88		11
5	*G. ferruginea*	0.42	0.72		4.76		0.06	0.42	5.54	13	9
6	*O. africana*	0.84	0.91	7.79	4.76	0.13	0.24	8.76	5.92	7	8
7	*V. senegal*	0.37		2.60		22.66		25.63		5	
8	*V. lahai*	1.19	0.48	6.49	2.38	0.50	0.59	8.18	3.45	8	10
9	*V. etbaica*	35.91	52.89	18.18	16.67	57.05	70.64	111.14	140.20	1	1
10	*V. nilotica*		0.24		1.19		0.36		1.79		13
11	*V. oerfota*	0.23	4.19	1.30	3.57		0.27	1.53	8.02	12	7
12	*V. sayal*	8.99	9.53	16.88	16.67	11.83	12.42	37.70	38.62	3	3
13	*V. tortolis*	14.55	17.61	16.88	15.48	5.29	5.99	36.73	39.08	4	2
14	Gofero	2.56	1.35	7.79	8.33	0.31	0.29	10.66	9.97	6	6
15	Tsechie	0.46		1.30		0.84		2.59		11	

Discussion

The floristic composition result revealed that species from the Fabaceae family are dominant in both the EX-SWC area and the adjacent EX area which might be associated with the nitrogen-fixing ability of the species. The current findings showed that the diversity of woody plants in the EX-SWC area was relatively higher than in the adjacent EX area. This result could indicate that the moisture harvesting structures established in the EX area might have played a role in improving the diversity of woody plants. This result corresponds with the findings of Wasie and Yimer (2020) whose findings revealed that the diversity of woody species was significantly higher in the EX-SWC area ($p<0.05$) compared to the adjacent EX area. The measured diversity value in the present EX-SWC study area (five years of age) was relatively higher than other similar findings of other exclosure areas of different ages that do not have moisture harvesting structures (Birhane et al., 2007; Tekenso, 2012; Dimtsu et al., 2018; Sinaro and Doboch, 2021). Tekenso (2012), Dimtsu et al. (2018), Sinaro and Doboch (2021), in 8, 10 and 15 years of age exclosure area recorded a diversity value for the woody plants of 1.4, 1.4, 0.76, correspondingly. Studies have indicated soil and water conservation measures can help to reduce soil loss and improve the regeneration of woody plants (Asefa et al., 2003; Carla et al., 2003; Mekuria et al., 2007; Siyum et al., 2019; Wasie and Yimer, 2020). However, the present result on the diversity value of the EX-SWC area is relatively lower than other similar study findings in an EX area where there were no moisture harvesting structures (Tefera, 2015; Eshetie et al., 2020). Tefera (2015) and Eshetie et al. (2020) recorded a diversity value of 3.4 and 1.77 in 5 and 10 years of age of an EX area. Similarly, Getseselassie (2012) and Asmare and Gureb (2019) recorded in an unknown age of EX area a diversity value of 2.94 and 1.7 where there were no moisture harvesting structures, correspondingly. The differences in the diversity value of the species in the current study area relative to other similar studies might be related to the differences in the agroecology of the area, level of degradation, disturbances etc.

The relative density of trees and also seedlings in the EX-SWC area was also relatively higher than the adjacent EX area which could also show that the moisture harvesting structures established in the EX area facilitated the regeneration of woody plants. This result corresponds with the findings of Dimtsu et al. (2018) and Wasie and Yimer (2020) whose results showed that the density of woody species was significantly higher in the EX-SWC area as compared to their adjacent study EX area. However, the present study findings in the EX area was relatively lower than other similar study findings in the EX area (Birhane et al., 2007; Tekenso, 2012; Tefera, 2015; Eshetie et al., 2020; Sinore and Doboch, 2021). These differences in the density of woody stems/ha in the EX area with other similar EX area findings could be associated with the age of the EX area, availability of soil seed banks, level of degradation etc. The relative density of trees for the DBH classes of 1-5 cm, 5.1-10 cm, and 10.1-15 cm in the EX-SWC area was greater than the relative density of trees in a similar DBH class of the EX area. Similarly, the relative density of seedlings in the height classes of 1-15.1 cm, 30.1-45 cm and 45.1-60 cm in the EX-SWC area were relatively higher than in the adjacent EX area. These results may show that the moisture harvesting structures established in the exclosure area, hold water, recharge into the ground, and the moisture will be available for the growth of the plants in the dry season and facilitate the regeneration. Studies showed that soil moisture is the basic resource for the growth and productivity of trees and conservation of moisture helps in improving the growth and productivity of trees (Sumbali et al., 2012; Yitbarek et al., 2012).

The importance value index is a measure of how dominant a species is in a given forest area. For the common species recorded in both the EX area and EX-SWC area, the IVI value of most of the species recorded in the EX-SWC was relatively higher than in the EX area. This may show that the EX-SWC structures facilitated the distribution of the species much better than in the EX area. The results further showed that in both the EX area and the adjacent EX-SWC area, the Acacia species are dominant. This could show that these species can regenerate in a degraded land much better than the other identified species in the study area. The relatively better regeneration of the Acacia species relative to the other identified species in the area could be associated with the nitrogen-fixing ability of the species. Studies showed that nitrogen fixing species, like Acacia, have a superior capacity to grow quickly in poor substrates and to withstand the harsh conditions in degraded soils (Wang et al., 2010; Chaer et al., 2011)

Conclusion

The present findings indicated that in an effort to restore the woody plants in the degraded land, soil and water conservation measures established in combination with the area exclosure measure facilitated the regeneration of woody plants relatively better than the adjacent only exclosure measure. Therefore, we recommend in restoration of woody plants in degraded areas, to apply soil and water conservation measures in combination with area exclosure since it facilitates the regeneration of woody plants.

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