






The Open Environmental Research Journal

Content list available at: <https://openenvironmentalresearchjournal.com/>



RESEARCH ARTICLE

Diversity of Woody Species and Biomass Carbon Stock in Response to Exclosure Age in Central Dry Lowlands of Ethiopia

Temima Ibrahim¹ , Fikrey Tesfay^{2,*}  and Bethel Geremew² 

¹Department of Forestry, College of Agriculture, Wollo University, Dessie, Ethiopia

²Department of Natural Recourse Management, College of Agriculture and Natural Resources Sciences, Debre Birhan University, Debre Birhan, Ethiopia

Abstract:

Objective:

Empirical evidence on the potential of area exclosure in the restoration of severely degraded lands is crucially important. Thus, a study was conducted to examine the influence of exclosure age on vegetation structure, diversity, and biomass carbon stock in the central dry lowland of Ethiopia.

Methods:

Exclosures of 5, 15, >20 years old, and adjacent open grazing land were selected. Data on vegetation were collected using 20 × 20 m sampling quadrats which were laid along parallel transect lines.

Results:

The result showed that 17 woody species which represent 9 families were recorded at exclosures and open grazing lands. Shannon-Wiener (H') diversity index ranged from 0.74 (open grazing land) to 2.12 (middle age exclosure). Shannon evenness (E) index was higher in the middle age exclosure (0.80). Woody species basal area and tree density significantly ($p < 0.05$) increased with increasing exclosure age. The Aboveground woody biomass significantly ($p < 0.05$) varied from 12.60 (open grazing land) to 68.61 Mg ha⁻¹ (middle age exclosure). Similarly, the aboveground biomass (AGB) carbon stocked was significantly ($p < 0.05$) higher in the middle (32 Mg ha⁻¹) and old age exclosures (31 Mg ha⁻¹).

Conclusion:

This study indicated that exclusion can restore the degraded vegetation and sequester and stock more atmospheric carbon dioxide in the aboveground biomass. Therefore, open degraded grazing land of the lowland areas can be restored into a promising stage through area exclosure land use management.

Keywords: Acacia species, Biomass, Degraded landscape, Grazing land, Woody species, Vegetation structure.

Article History

Received: August 04, 2020

Revised: October 15, 2020

Accepted: February 14, 2021

1. INTRODUCTION

Land degradation which is a long lasting decline in the provision capacity of an ecosystem to provide goods and services (Appanah *et al.*, 2015) is widely recognized as a serious global problem, particularly in developing countries. When coupled with climate change effects, it undermines food security (Etter, 2016). The Ethiopian highlands have been degraded and have reached catastrophic levels over the last

three centuries (Berisso, 1995; Nyssen *et al.*, 2015). The chief causes of land degradation in the country are population pressure and limited agricultural technologies, inappropriate land use and cultivation into marginal lands, and deforestation (Haile *et al.*, 2006; Nyssen *et al.*, 2008a; Hurni *et al.*, 2010), socio-political changes (Dessie and Christiansson, 2008), and unbalanced free grazing with the still-increasing livestock populations (Taddese, 2001; Abiyu *et al.*, 2011). Intensified use of land and dwindling of the remnant forests in central Ethiopia are further exacerbating land degradation (Abebe *et al.*, 2014).

* Address correspondence to this author at the Department of Natural Recourse Management, College of Agriculture and Natural Resources Sciences, Debre Birhan University, Debre Birhan, Ethiopia; E-mail: fikreytesfay@gmail.com

In Ethiopia, land degradation impairs the capacity of forests, to provide ecosystem services (Solomon *et al.*, 2018) and the land to contribute to food security (Bishaw, 2001). It also results in significant environmental degradation and loss of forest biodiversity (Lemenih and Kassa, 2014). Estimates show that the country is losing up to 1636 km² yr⁻¹ forest cover, which is one of the highest in Africa (Tolera *et al.*, 2008). Land degradation in Ethiopia has not only resulted in biomass loss, but also an increase in risks of desertification (Girmay *et al.*, 2008). Further deforestation contributed to climate change by causing changes in the earth's atmosphere in the amounts of greenhouse gases. Land resources degradation in Ethiopia resulted in erosion induced soil carbon depletion rate of up to 970 kg ha yr⁻¹ (Shiferaw *et al.*, 2013). Land degradation increases the vulnerability of people to the adverse effects of climate variability and change. As a result of unfavorable climate conditions, poor agricultural technologies, and high population growth, the magnitude of land degradation is more severe in arid regions of Ethiopia (Meaza *et al.*, 2017).

The ecological restoration, which is the process of assisting the rehabilitation of degraded ecosystems (Ruiz-Jaen and Aide, 2005) has been an important approach to mitigate human pressures on natural ecosystems and improve ecosystem services (Mekuria *et al.*, 2015). To rehabilitate the vast degraded landscapes and combat environmental problems, area enclosures have commenced since the 1980s in the northern highlands of Ethiopia (Aerts *et al.*, 2009). Enclosures are areas that are excluded from the disturbance of domestic animals and humans to promote the natural regeneration of plants and reduce land degradation (Aerts *et al.*, 2009). The ultimate goal of restoration using enclosure is to create a self-supporting ecosystem that is resilient to perturbation without further assistance (Ruiz-Jaen and Aide, 2005). Over the past two decades, enclosures have been expanded to the central part of the country (Mengistu *et al.*, 2005; Yirdaw and Monge, 2018). Effective restoration of degraded ecosystems is one of the imperative efforts to ensure sustainable food and biomass supply to the heavily agricultural dependence of the population of the country while maintaining ecological integrity (Lemenih, 2006).

Restoration of degraded lands through the establishment of enclosures is crucial to support people and food systems as well as to adapt to climate variability (Mekuria *et al.*, 2017). Studies have indicated that after enclosure was established on degraded landscape vegetation restored (Birhane *et al.*, 2006; Mekuria and Yami, 2013; Mekuria *et al.*, 2015; Ibrahim, 2016). Enclosures can enhance soil nutrients such as total soil nitrogen, available phosphorus, and cation exchange capacity (Descheemaeker *et al.*, 2006b; Mekuria and Aynekulu, 2013; Abebe *et al.*, 2014). Furthermore, enclosure can improve soil organic carbon (Yimer *et al.*, 2015; Qasim *et al.*, 2017) and increase the potential of atmospheric carbon sequestration (Feyisa *et al.*, 2017). Area enclosures are likely to improve soil carbon stock thereby increasing the amount and quality of the biomass that is recycled into the soil (Chen *et al.*, 2012). Restoration of vegetation in severely degraded lands in dry regions has a considerable potential to increase carbon storage while improving soil quality (Li *et al.*, 2012).

Enclosure land management began to be practiced fifteen years ago to restore the degraded landscapes in Kewet district, which is part of the central dry lowlands of Ethiopia (Bizuayehu and Tefera, 2008). Unlike enclosures on other parts of the country, less attention has been given to enclosure in the central dry lowland of Ethiopia in the assessment of their effectiveness in the restoration of vegetation. Little is known about aboveground biomass and carbon stock of enclosures in response to their age (Giday *et al.*, 2013). Earlier most studies conducted on area enclosures in Ethiopia focused on the comparison of vegetation composition and soil properties with adjacent grazing lands (Abiyu *et al.*, 2011; Mekuria *et al.*, 2018; Haftom *et al.*, 2019). Except for very few (Descheemaeker *et al.*, 2006a; Mekuria and Yami, 2013), change in vegetation composition along chronosequence is not yet well studied. Despite the number of studies, most studies lack integrating climate change issues i.e., determination of carbon stock. This helps the management and policy decision-makers related to the expansion of such land use management to restore degraded lands of the lowland areas. Therefore, this study aimed to quantify 1) the vegetation structure and diversity and 2) aboveground biomass and carbon stock of different aged enclosures and adjacent open grazing land in the central dry lowland of Ethiopia.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

The study was conducted in Kewet district situated 213 km northeast of Addis Ababa at the foot of the eastern escarpment of the central Ethiopian highlands. It is located within the coordinates of 9°49' and the 10°11' latitude N and 39°45' to 40°6' longitude E. Administratively, Kewet district lies within the North Shewa Administrative Zone of the Amhara National Regional State (Fig. 1). The altitude ranges from 1080 to 3151 m a.s.l. Based on 10 years (2007–2016) of data from the Shewa Robit meteorology station, the area receives a mean annual rainfall of 1007 mm and a mean annual minimum and maximum temperature of 16.5 and 31°C, respectively. Kewet district lay in Robit Valley which is widely covered by basalt and related pyroclastics rock types of tertiary age (Tefera *et al.*, 1996). According to World Reference Base (WRB), Eutric Cambisols and pellic vertisols are the dominant soil groups in the alluvial fan area of the district lies the lower areas are dominantly covered with Calcic gleysols and Calcic cambisols (Paris, 1986). Over 41 and 26% of the district's land is covered by cultivated land, and forest and shrubland, respectively (Tesfay *et al.*, 2020). Area enclosure practice is common in the district, which covers 15 km² of the total land coverage (Bizuayehu and Tefera, 2008). According to Ethiopia's Central Statistical Agency (CSA) population projection for all regions at wereda level from 2014 – 2017, the district has a total population of 147,093 with a population density of 197 persons per km² (CSA, 2013).

2.2. Sampling Technique and Sampling Size

Three enclosure sites which are 5, 15, and >20 years old and one adjacent open grazing land were selected purposively which hereafter is referred to as young, middle, and old age enclosure, respectively. Then, three parallel transect lines

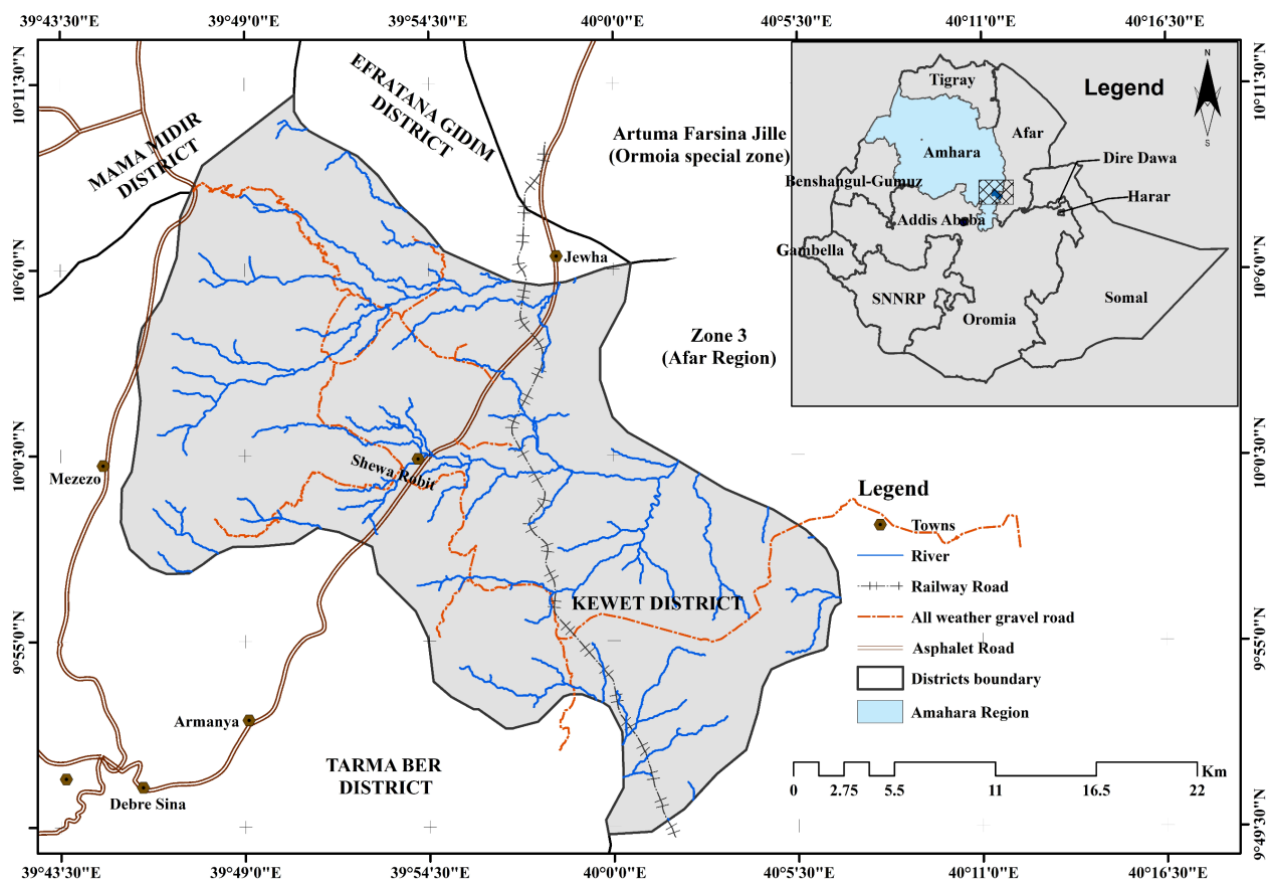


Fig. (1). Map of the study site.

(which were considered as replicates) across the selected exclosures and open grazing land were laid. Quadrats measuring 20 × 20 m (400 m²) were laid down along the parallel line transects at a regular distance (Kent, 2012). Data on woody species type, height, and diameter at breast height (dbh) of individuals with dbh > 2 cm were collected from quadrats along each line transects within each site. The total number of individuals of each wood species seedling and saplings < 1.5 m height was counted and recorded in each quadrat (Kent, 2012). Hypsometer and caliper were used to measure the height and dbh of the tree, respectively. A total of 36 sample plots was used to collect data on woody vegetation. The woody species were identified directly in the field using (Hedberg and Edwards, 1989; Edwards *et al.*, 1995; Hedberg *et al.*, 2003, 2006). Geographical information such as location, elevation, slope, and aspect of each plot was recorded using a geographical positioning system (GPS).

2.3. Vegetation Data Analyses

2.3.1. Floristic, Diversity and Structure Analysis of Woody Species

The similarity in the floristic composition of woody species between the different age of exclosures and adjacent open grazing land was computed using Sorensen's measure of similarity (Magurran, 2004) as follows:

$$C_s = \frac{2a}{2a + b + c} * 100 \tag{1}$$

where, a = is the number of species common to both exclosures and adjacent open grazing land, b = is the number of species on exclosure 1 or adjacent open grazing land (site 1) only, and c = is the number of species on exclosure 1 or adjacent open grazing land (site 2) only. Often the coefficient is multiplied by 100 to give a percentage similarity figure. Species richness is a biologically appropriate measure of alpha (α) diversity and it refers to the number of species in a particular area (Newton, 2007). The diversity of woody species was determined by the Shannon-Wiener diversity (H') index. The index takes into account the species richness and the proportion of each woody species in all sampled quadrats (Teketay *et al.*, 2018). Shannon-Wiener diversity was calculated using the following equation (Magurran, 2004):

$$H' = - \sum_{i=1}^s p_i \ln p_i \tag{2}$$

where, H' = is a Shannon-Wiener (H') diversity index, P_i= is the proportion of individuals of woody species found in the quadrats, S= is the number of woody species and ln= natural logarithm. Woody species evenness which is a measure of similarity of the abundances of the different woody species in

the sampled enclosure and grazing land sites (Teketay *et al.*, 2018) was determined using Shannon evenness measure (E). It was calculated using the following equation (Magurran, 2004; Kent, 2012):

$$J = \frac{H'}{H_{\max}} = \frac{-\sum_{i=1}^s p_i \ln p_i}{\ln S} \quad (3)$$

The woody species structure was determined through quantitative analysis using parameters such as frequency, density (number of trees ha^{-1}) and basal area ($\text{m}^2 \text{ha}^{-1}$). Frequency is the number of times a species is recorded in a given number of plots and it is expressed as the percentage of quadrats in which a particular species is present (Newton, 2007). Density is the number of individuals of a species per unit area (Kent, 2012). Basal area (BA) is the cross-sectional area of a tree estimated at breast height (1.3 m), which is expressed in m^2 . Basal area was calculated using the following equation (Newton, 2007):

$$g = \frac{\pi d^2}{4} \quad (4)$$

where: g = is a basal area (m^2), and d = is the diameter at breast height of a tree (m).

The importance value index (IVI) is used as a measure of

$$\text{AGB} = 0.454 \times \text{dbh}^{1.848} \quad \text{adj-R}^2 = 0.815, \text{rRMSE} (\%) = 13, \text{rBias} (\%) = 1 \quad (9)$$

where, AGB = Aboveground biomass (kg tree^{-1}) dbh = diameter at breast height (cm) rRMSE = relative root mean square error, and rBias = relative bias

Belowground biomass is often estimated from root: shoot ratios by taking 28% of the aboveground biomass ((Intergovernmental Panel on Climate Change (IPCC) *et al.*, 2006;) and it was estimated as follows:

$$\text{Belowground biomass (BGB)} = \text{AGB} \times 0.28 \quad (10)$$

where, AGB = Aboveground biomass (kg tree^{-1})

Then both the above and belowground biomass were converted into carbon by multiplying the aboveground (or belowground) biomass by 0.47 (IPCC, 2006):

$$\text{Aboveground (or belowground) biomass carbon stock} = Y \times 0.47 \quad (11)$$

where, Y = wood biomass $^{-1}$ (kg)

2.4. Statistical Data Analysis

Data on vegetation structure, composition, aboveground biomass, and aboveground biomass carbon stock were subjected to a one-way analysis of variance (ANOVA) following a generalized linear model (GLM) of SAS 9.2 software. Post Hoc Test of Tukey's Honest Significant Difference (HSD) test was used for mean separation if the analysis of variance showed statistically significant differences ($p < 0.05$).

species composition that combines frequency, abundance, and dominance values. The ecological importance of woody species (IVI) was determined using relative frequency, abundance, and dominance parameters according to the formula of (Kent, 2012):

$$\text{Relative abundant (RA)} = \frac{\text{Number of individuals of a species}}{\text{Total number of Individuals}} \times 100 \quad (5)$$

$$\text{Relative dominance (RD)} = \frac{\text{Dominance* of a species}}{\text{Dominance of all species}} \times 100 \quad (6)$$

$$\text{Relative frequency (RF)} = \frac{\text{Frequency of a species}}{\text{Frequency of all species}} \times 100 \quad (7)$$

$$\text{IVI of each species} = \text{RA} + \text{RD} + \text{RF} \quad (8)$$

where, *Dominance is defined as the mean basal area per tree, multiplied by the number of trees of the species.

2.3.2. Aboveground Woody Biomass and Carbon Stocks Estimation

To estimate the aboveground woody biomass (AGB) in the enclosures and adjacent open grazing land, an allometric equation developed (Tetemke *et al.*, 2019) for multispecies of the dry Afromontane forests in dry mid-highlands of Northern Ethiopia was used.

3. RESULTS AND DISCUSSION

3.1. Floristic Composition

A total of 21 species that represent 9 families were recorded both in the enclosures and adjacent open grazing land. Woody species richness ranged from 10 species in the open grazing land to 14, 15, and 17 species in the middle, old, and young age enclosures, respectively. This result is comparable to similar studies conducted by Haftom *et al.*, (2019) in Tigray, Northern Ethiopia, and Abiyu *et al.*, (2011) in South Wollo, Northern Ethiopia. which reported 17 and 14 woody species, respectively in area enclosures. However, the result of this study is lower when compared to reports of Mekuria *et al.*, (2018) which reported 32 woody species in enclosures in the North-Western Ethiopia and Teketay *et al.*, (2018) which recorded 35 woody species in an enclosure in the Mopane woodland in northern Botswana.

Analysis of the Sorensen's similarity index showed that between all sites there was over 50 and 40% similarity of woody species and family, respectively (Table 1). The woody species in the open grazing land were less similar to the woody species in the area enclosures, whereas the similarity of woody species between enclosure was higher than with the open grazing land. Of the total woody species encountered in the study area, six were common in all the enclosures and open grazing land and 11 species were present only in the enclosures. One woody species (*Prosopis juliflora*) was only recorded in the open grazing land and three woody species

(*Balanites aegyptiaca*, *Berchemia discolor*, and *Grewia ferruginea*) were recorded only in the young age enclosure. The existence of *Prosopis juliflora* indicated that there is an encroachment of exotic and invasive tree species on the degraded open grazing land. Reports have indicated that certain woodlands in the Eastern Ethiopian highlands are causing some socio-cultural damage (FAO, 2015). In the study area and the nearby Afar region, the encroachment of *Prosopis juliflora* is becoming a great concern to the communal rangeland.

Table 1. Sorensen's similarity index of woody species and family of enclosures and open grazing land.

Land use	Species similarity (%)				Family similarity (%)			
	OGL	Yo-ex	Mi-ex	Ol-ex	OGL	Yo-ex	Mi-ex	Ol-ex
Open grazing land	100.00	51.85	58.33	58.33	100.00	40.00	100.00	100.00
Young age enclosure	-	100.00	75.00	77.42	-	100.00	71.43	80.00
Middle age enclosure	-	-	100.00	93.33	-	-	100.00	93.33
Old age enclosure	-	-	-	100.00	-	-	-	100.00

OGL= open grazing land, Yo-ex = young age enclosure, Mi-ex = middle age enclosure, and Ol-ex = old age enclosure.

Of the total family recorded in the study area, Fabaceae was observed in all the enclosures and open grazing land, and Olacaceae was only recorded in the young age enclosures. Only three family names, i.e., Boraginaceae, Fabaceae, and Tiliaceae were observed in the open grazing land (Tables 4-7). As in many other places of Ethiopia, the Fabaceae family contributed the greatest number of species in the study area (Mekuria and Yami, 2013; Mekuria *et al.*, 2015; Gebremedihin *et al.*, 2018). Despite its consistency, both family numbers and species numbers increase with an increase in age of enclosure.

Table 2. Woody species Shannon index diversity and Shannon evenness.

Land Use	Species Richness	Shannon Index (H')	Shannon Evenness (E')
Open grazing land	10	0.74	0.32
Young age enclosure	17	2.02	0.71
Middle age enclosure	14	2.12	0.80
Old age enclosure	15	2.06	0.76

3.2. Woody Species Diversity

The Shannon-Wiener (H') index ranged from 0.74 at the open grazing land to 2.12 at the middle age enclosure (Table 2). According to Magurran, (2004), the Shannon-Wiener (H') diversity index in the enclosures can be rated as moderate whereas the diversity in the open grazing land was very low. Usually, the value of the Shannon-Wiener diversity index ranged from 1.5 to 3.5 and rarely surpassed 4 for a very huge number of species (Magurran, 2004). Shannon-Wiener diversity index in the study area indicated that enclosures can improve the diversity of woody species in the degraded open

grazing lands. The changes in species richness were also evident in the Shannon-Wiener. The mean value of the Shannon-Wiener index of this study is in line with other similar studies conducted by Mekuria *et al.*, (2018) in West Gojam, North-Western Ethiopia, and Gebremedihin *et al.*, (2018) in the highlands of Tigray, Northern Ethiopia.

The Shannon evenness (E') index was also lower (0.32) at the grazing land and it was higher (0.80) in the middle age enclosure (Table 2). The higher the evenness value, the more even the distribution of species is at a site (Kent, 2012). Thus, the result of this study showed that there was a better equitable distribution of individual woody species in the enclosure than open grazing land. The high Shannon evenness value in the middle age enclosure might be attributed to the low anthropogenic disturbance in the enclosures since it is excluded from unmanaged access. In line with this study Teketay *et al.*, (2018) reported an evenly distributed individual of woody species in area enclosure than in the open grazing area in Mopane woodland in northern Botswana.

3.3. Woody Species Structure

3.3.1. Basal Area and Tree Density

As indicated in (Table 3), significantly ($p < 0.05$) higher woody species basal area was observed in the middle ($20 \text{ m}^2 \text{ ha}^{-1}$) and old age enclosure ($20 \text{ m}^2 \text{ ha}^{-1}$) than the young age enclosure ($6 \text{ m}^2 \text{ ha}^{-1}$) and open grazing land ($3 \text{ m}^2 \text{ ha}^{-1}$). This indicated an increase of volume and area occupied by woody species with enclosure age. The highest basal area in the enclosures could be due to the relatively long period of exclusion from interference which allowed woody species to grow bigger. Other similar studies conducted in North-Western Ethiopia by Mekuria *et al.*, (2018) and in Eastern Tigray, Ethiopia by Birhane *et al.*, (2007) reported higher basal area in area enclosures than adjacent open grazing lands. Furthermore, the mean woody species basal area of enclosures was higher than other similar studies conducted in different parts of Ethiopia (Mekuria *et al.*, 2018; Haftom *et al.*, 2019).

Table 3. Mean \pm S.E of basal area and tree density of enclosures and open grazing land.

Land Use	Basal Area ($\text{m}^2 \text{ ha}^{-1}$)	Tree Density (ha^{-1})
Open grazing land	3.54 \pm 1.75 ^b	200.00 \pm 44.10 ^b
Young age enclosure	6.29 \pm 1.54 ^b	469.44 \pm 28.50 ^a
Middle age enclosure	20.35 \pm 3.92 ^a	483.33 \pm 26.02 ^a
Old age enclosure	20.29 \pm 5.09 ^a	559.33 \pm 81.86 ^a
p-value	< 0.001	< 0.001
CV%	81.26	35.28

Means \pm S.E. with different letters within a column are significantly different ($p < 0.05$) (Tukey's test HSD).

Tree density showed a significant difference ($p < 0.05$) between enclosures and the open grazing lands. It was ranged from 200 trees ha^{-1} in the grazing land to 559 trees ha^{-1} in the old age enclosure (Table 3). Tree density showed an increasing trend with increasing age of the enclosure. It is observed in this study that woody species density was positively influenced by

exclosures. The tree density in the old exclosure was two and a half times higher than the tree density in the open grazing land. Similar studies were conducted by Mekuria *et al.*, (2018) in West Gojam, North-Western Ethiopia, and by Teketay *et al.*, (2018) in Mopane woodland in northern Botswana which showed a higher woody species density in exclosure than their adjacent grazing land. However, compared to these studies, the mean tree density in the study area was very small. This might attribute to differences in the management practice of the exclosures.

Table 4. Tree density (ha⁻¹), RF (%), RA (%), RD (%) and IVI (%) of woody species of open grazing land.

Species Names	Family	TD	RF	RA	RD	IVI
<i>Acacia tortilis</i> (Forssk.) Hayne.	Fabaceae	53.13	17.24	22.37	34.35	73.96
<i>Acacia nilotica</i> (L.) Willd. Ex Del.	Fabaceae	37.5	6.9	15.79	24.44	47.12
<i>Acacia etbaica</i> Schweinf.	Fabaceae	43.75	13.79	18.42	11.22	43.43
<i>Acacia senegal</i> (L.) Willd.	Fabaceae	15.63	13.79	6.58	15.05	35.43
<i>Dichrostachys cinerea</i> (L.) Wight & Am.	Fabaceae	28.13	10.34	11.84	2.9	25.09
<i>Ehretia cymosa</i> Thonn.	Boraginaceae	15.63	10.34	6.58	3.23	20.15
<i>Acacia seyal</i> Del.	Fabaceae	12.5	6.9	5.26	7.48	19.64
<i>Grewia villosa</i> Willd.	Tiliaceae	15.63	10.34	6.58	0.47	17.39
<i>Acacia brevispica</i> Harms.	Fabaceae	12.5	6.9	5.26	0.54	12.7
<i>Prosopis juliflora</i> (Sw.) DC.	Fabaceae	3.13	3.45	1.32	0.33	5.09
-	-	-	100	100	100	300

TD = Trees density, RF = Relative frequency, RA = Relative abundant, RD = Relative dominance and IVI = Important Value Index.

Table 5. Tree density (ha⁻¹), RF (%), RA (%), RD (%) and IVI (%) of woody species of young age exclosure.

Species Names	Family	TD	RF	RA	RD	IVI
<i>Acacia brevispica</i> Harms.	Fabaceae	205.56	4.55	43.79	34.5	82.83
<i>Acacia tortilis</i> (Forssk.) Hayne	Fabaceae	41.67	15.91	8.88	32.73	57.52
<i>Dichrostachys cinerea</i> (L.) Wight & Am.	Fabaceae	38.89	13.64	8.28	2.07	23.99
<i>Acacia senegal</i> (L.) Willd.	Fabaceae	13.89	9.09	2.96	11.83	23.88
<i>Euphorbia cactus</i> Boiss.	Euphorbiaceae	55.56	9.09	11.83	0.65	21.57
<i>Delonix regia</i> (Boj. ex Hook.) Raf.	Fabaceae	16.67	9.09	3.55	3.58	16.22
<i>Acacia nilotica</i> (L.) Willd. Ex Del.	Fabaceae	13.89	4.55	2.96	8.66	16.16
<i>Euclea divinomm</i> Murr	Ebenaceae	27.78	6.82	5.92	0.2	12.94
<i>Grewia villosa</i> Willd.	Tiliaceae	11.11	6.82	2.37	0.17	9.36
<i>Grewia bicolor</i> Juss.	Tiliaceae	13.89	4.55	2.96	0	7.51
<i>Balanites aegyptiaca</i> (L.) Del.	Balanitaceae	2.78	2.27	0.59	3.52	6.39
<i>Berberia discolor</i> (Klotzsch) Hemsl.	Rhamnaceae	11.11	2.27	2.37	1.35	5.99
<i>Grewia ferruginea</i> Hochst. ex A. Rich.	Tiliaceae	5.56	2.27	1.18	0.02	3.48
<i>Acacia oerfota</i> (Forssk.) Schweinf.	Fabaceae	2.78	2.27	0.59	0.56	3.43
<i>Ziziphus spina-ehristi</i> (L.) Des.	Rhamnaceae	2.78	2.27	0.59	0.1	2.96
<i>Ximenia americana</i> L.	Olcaceae	2.78	2.27	0.59	0.04	2.9
<i>Acacia seyal</i> Del.	Fabaceae	2.78	2.27	0.59	0	2.87
-	-	-	100	100	100	300

TD = Tree density, RF = Relative frequency, RA = Relative abundant, RD = Relative dominance and IVI = Importance Value Index.

3.3.2. Important Value Index

Analysis of IVI species in the open grazing land showed that *Acacia tortilis* (74%), *Acacia nilotica* (47%), and *Acacia etbaica* (43%) were the most important valued species (Table 4). In the young age exclosure *Acacia brevispica* (82%), *Acacia tortilis* (58%), and *Dichrostachys cinerea* (24%) were woody with high IVI value (Table 5). *Acacia senegal* (67%), *Acacia brevispica* (61%), and *Acacia nilotica* (58%) in the middle age exclosure (Table 6) and *Acacia senegal* (99%), *Acacia nilotica* (57%), and *Acacia brevispica* (36%) in old exclosure (Table 7) were the woody species which had high IVI value. Analysis of IVI in the study area showed that *Acacia senegal* was one of the woody species which make the top five IVI species across all the exclosures and the open grazing land. In addition to this, *Acacia brevispica* is one of the species which makes the top five IVI species in all the exclosures.

The IVI result has also shown that *Acacia* tree species were the most ecologically important species in both grazed and exclosures. The importance value index indicated the relative ecological importance of the woody species in the study area (Kent, 2012). The dry lowland area of Ethiopia is known for its dominance by *Acacia* tree species (Mengistu *et al.*, 2005; Nyssen *et al.*, 2008b; Birhane *et al.*, 2010; Yimer *et al.*, 2015). Feyisa *et al.*, (2017) in Borana rangelands, Southern Ethiopia has reported that *Acacia tortilis*, *Acacia seyal*, and *Balanites aegyptiaca* dominated exclosure. *Acacia* species are among the common woody plants that naturally grow in many dry rangelands in sub-Saharan Africa (Yayneshet *et al.*, 2008). These species are important litter producers in the exclosures established on degraded lands (Descheemaeker *et al.*, 2006a) and subsequently, improve soil fertility (N₂-fixing) and increase SOC stock (Nair *et al.*, 2009; Abaker *et al.*, 2016).

Table 6. Tree density (ha⁻¹), RF (%), RA (%), RD (%) and IVI (%) of woody species of middle-aged exclosure.

Species names	Family	TD	RF	RA	RD	IVI
<i>Acacia senegal</i> (L.) Willd.	Fabaceae	113.9	12.5	17.83	36.27	66.59
<i>Acacia brevispica</i> Harms.	Fabaceae	197.2	12.5	30.87	17.41	60.78
<i>Acacia nilotica</i> (L.) Willd. Ex Del.	Fabaceae	80.56	12.5	12.61	32.66	57.77
<i>Delonix regia</i> (Boj. ex Hook.) Raf.	Fabaceae	47.22	9.72	7.39	5.61	22.73
<i>Euphorbia cactus</i> Boiss.	Euphorbiaceae	61.11	9.72	9.57	1.97	21.25
<i>Grewia bicolor</i> Juss.	Tiliaceae	27.78	6.94	4.35	1.56	12.85
<i>Ehretia cymosa</i> Thonn.	Boraginaceae	16.67	6.94	2.61	2.06	11.61
<i>Grewia villosa</i> Willd.	Tiliaceae	25	5.56	3.91	1.24	10.71
<i>Dichrostachys cinerea</i> (L.) Wight & Am.	Fabaceae	16.67	5.56	2.61	0.02	8.18
<i>Euclea divinomm</i> Murr	Ebenaceae	22.22	4.17	3.48	0.02	7.66
<i>Apodytes dimidiata</i> E. Mey. Ex Am.	Icacinaceae	8.33	4.17	1.3	0.51	5.98
<i>Acacia etbaica</i> Schweinf.	Fabaceae	8.33	4.17	1.3	0.01	5.48
<i>Acacia tortilis</i> (Forssk.) Hayne	Fabaceae	8.33	2.78	1.3	0.67	4.75
<i>Acacia oerfota</i> (Forssk.) Schweinf.	Fabaceae	2.78	1.39	0.43	0	1.83
<i>Ximenia americana</i> L.	Olacaceae	2.78	1.39	0.43	0	1.83
-	-	-	100	100	100	300

TD = Tree density, RF = Relative frequency, RA = Relative abundant, RD= Relative dominance and IVI = Importance Value Index.

Table 7. Tree density (ha⁻¹), RF (%), RA (%), RD (%) and IVI (%) of woody species of old age exclosure.

Species names	Family	TD	RF	RA	RD	IVI
<i>Acacia senegal</i> (L.) Willd.	Fabaceae	181.3	17.78	32.4	49.18	99.36
<i>Acacia nilotica</i> (L.) Willd. Ex Del.	Fabaceae	78.13	13.33	13.97	29.21	56.51
<i>Acacia brevispica</i> Harms.	Fabaceae	106.3	13.33	18.99	4.09	36.42
<i>Acacia tortilis</i> (Forssk.) Hayne	Fabaceae	18.75	8.89	3.35	9.71	21.96
<i>Acacia etbaica</i> Schweinf.	Fabaceae	21.88	8.89	3.91	6.69	19.49
<i>Euphorbia cactus</i> Boiss.	Euphorbiaceae	53.13	8.89	9.5	0.11	18.5
<i>Apodytes dimidiata</i> E. Mey. Ex Am.	Icacinaceae	28.13	6.67	5.03	0.05	11.74
<i>Dichrostachys cinerea</i> (L.) Wight & Am.	Fabaceae	21.88	4.44	3.91	0.51	8.86
<i>Delonix regia</i> (Boj. ex Hook.) Raf.	Fabaceae	15.63	4.44	2.79	0.08	7.32
<i>Ximenia americana</i> L.	Olacaceae	15.63	2.22	2.79	0.21	5.23
<i>Euclea divinomm</i> Murr	Ebenaceae	6.25	2.22	1.12	0.01	3.35
<i>Ziziphus spina-ehristi</i> (L.) Des.	Rhamnaceae	3.13	2.22	0.56	0.12	2.9
<i>Ehretia cymosa</i> Thonn.	Boraginaceae	3.13	2.22	0.56	0.01	2.79
<i>Grewia bicolor</i> Juss.	Tiliaceae	3.13	2.22	0.56	0.01	2.79
<i>Grewia villosa</i> Willd.	Tiliaceae	3.13	2.22	0.56	0	2.79
-	-	-	100	100	100	300

TD = Tree density, RF = Relative frequency, RA = Relative abundant, RD = Relative dominance and IVI = Importance Value Index.

3.3.3. Population Structure

The majority of the woody species in the study area had a height of below 5 m. The mean height of woody species was higher in the area exclosures than the open grazing land. Relatively the middle age exclosure and open grazing land have a higher number of woody species individuals > 5 m height (Figs. 2 and 4). The mean height of the species was 2.96±0.14, 2.37±0.08, 2.23±0.09, and 2.24±0.09 m for open grazing land, young, middle and old age exclosure, respectively, with the maximum height observed for *Acacia brevispica* and *Acacia senegal* (6.2 m) and the minimum for *Apodytes dimidiata* (0.2 m).

Diameter distribution of the community of all woody

species in the study area showed an inverted J shape (Fig. 3). In open grazing land, most of the woody species were in the middle diameter classes (11-20 cm) and less in the lower diameter classes. The mean diameter of individual woody species was 16.91±0.99, 9.30±0.71, 14.62±0.98, and 14.80±1.17 cm for open grazing land, young, middle, and old exclosure, respectively. The dominance of remnant trees which are old, large and taller trees and less scattered existence of saplings and younger trees in the open grazing land might be the reason for the higher mean diameter of individual trees in the open grazing land than the exclosure. The maximum diameter was observed for *Acacia senegal* (80 cm) and the minimum for *Dichrostachys cinerea*, *Grewia villosa*, *Ximenia americana*, and *Acacia brevispica* (3 cm).

Both the height and diameter distribution graphs (Figs. 2 and 3) of this study depict that the open grazing land was dominated by shrubs and trees while exclosures had a higher number of tree seedlings and saplings. Thus, exclusion of disturbance favored the higher number of seedlings and saplings. Furthermore, the inverted J shape distribution of woody species dbh in the exclosures indicated that exclosure created favorable conditions for an active and uniform regeneration of woody species in the degraded and open grazing land. The higher mean height and diameters of woody species in grazing land might be due to seedlings and saplings

exposed to domestic animals grazing and trampling. Due to exclusion from interference, there is a high probability of growing to the next diameter class in exclosures, that gives a better population structure. Similar investigations conducted in the highlands of Tigray, Northern Ethiopia by Negussie *et al.*, (2008), and Birhane *et al.*, (2017) have reported a higher abundance of tree seedling than adjacent open grazing lands. Other study by Teketay *et al.*, (2018) also found higher seedling density in area exclosure than the adjacent open grazing system in Mopane woodland in northern Botswana.

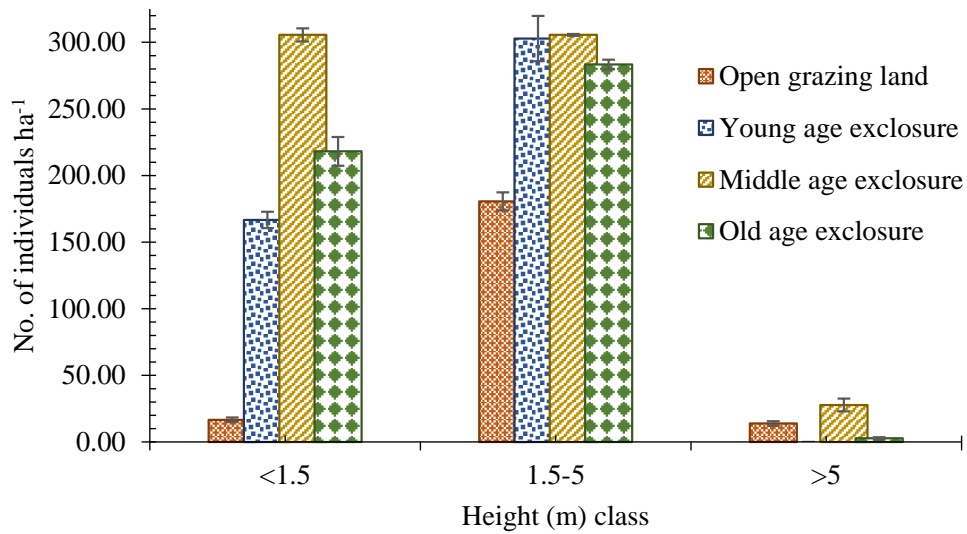


Fig. (2). Woody species height distribution in exclosures and open grazing land.

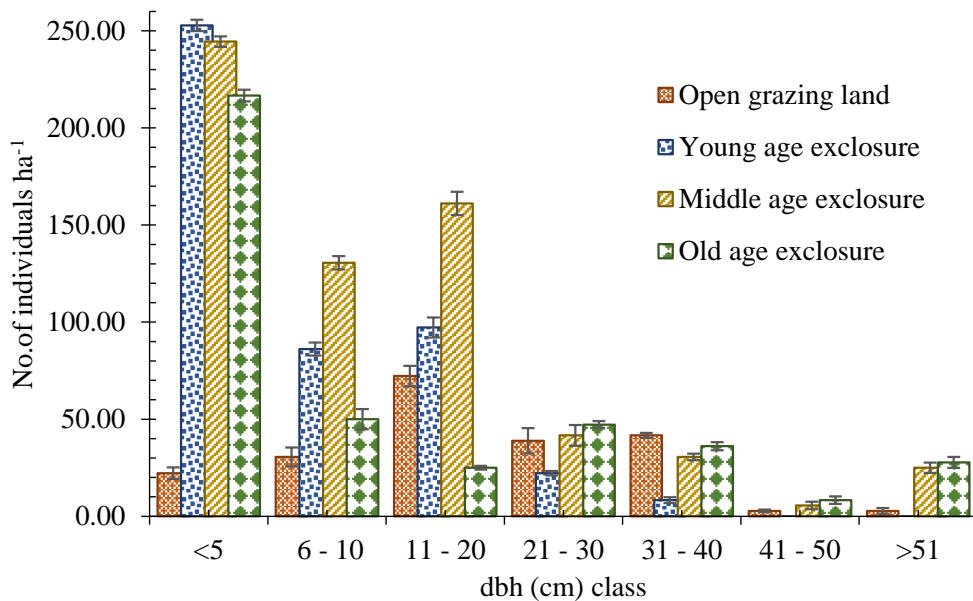


Fig. (3). Woody species diameter distributions in exclosures and open grazing land.



Fig. (4). Partial view of a) open grazing land, b) young age enclosure, c) middle age enclosure, and d) old age enclosure in the central dry lowland of Ethiopia.

3.4. Aboveground Woody Biomass and Carbon Stock

Aboveground biomass and belowground biomass showed statistically significant ($p < 0.05$) variation between exclosures and open grazing land (Table 8). Aboveground biomass ranged from 12.60 Mg ha^{-1} at the open grazing land to 86.61 Mg ha^{-1} in the middle age enclosure. Aboveground biomass quantified in this study mirrored the basa area which is significantly higher in the middle and old age exclosures. This might explain the higher AGB in the middle and old age exclosures. In a study

undertaken Mekuria *et al.*, (2018) in North-Western Ethiopia, it was indicated that exclosure land management can improve soil properties, which consequently supports the restoration of native vegetation and the accumulation of aboveground biomass. The result of this study is in line with findings of Yayneshet, (2011) in the Tigray region of northern Ethiopia and Mekuria and Yami, (2013) in the lowlands of Northern Ethiopia which reported higher aboveground biomass in exclosures than adjacent grazing lands.

Table 8. Mean± S.E values of AGB (Mg ha^{-1}), BGB (Mg ha^{-1}), AGB-C stock (Mg ha^{-1}) and BGB-C stock (Mg ha^{-1}).

Land Use	AGB	BGB	AGB-C	BGB-C
Open grazing land	12.60 ± 6.20^b	3.15 ± 1.55^b	5.92 ± 2.91^b	1.66 ± 0.82^b
Young age enclosure	22.81 ± 5.26^b	5.70 ± 1.31^b	10.72 ± 2.47^b	3.00 ± 0.69^b
Middle age enclosure	68.61 ± 12.47^a	17.15 ± 3.12^a	32.25 ± 5.86^a	9.03 ± 1.64^a
Old age enclosure	67.85 ± 15.96^a	16.96 ± 3.99^a	31.89 ± 7.50^a	8.93 ± 2.10^a
p-value	< 0.001	< 0.001	< 0.001	< 0.001
CV%	76.21	76.21	76.21	76.2

Means ±S.E. with different letters within a column are significantly different ($p < 0.05$) (Tukey's test HSD). AGB = Aboveground biomass, BGB = Belowground biomass, and C = Carbon.

The AGB carbon stock was significantly ($p < 0.05$) higher in the middle (32 Mg ha⁻¹) and old (31 Mg ha⁻¹) age exclosures whereas it was significantly lower in the open grazing land and young age exclosure. The BGB carbon stock followed a similar trend to the AGB carbon stock. The highest AGB carbon stock in the middle and old age exclosure could be associated with the high tree density and tree basal area. Except in the young exclosure, AGB and carbon stock had shown consistent increase from middle age to old exclosure age (Table 8). In line with this, several studies have indicated a significantly higher AGB carbon stock in exclosure than adjacent open grazing lands. For instance, studies conducted by Shimelse *et al.*, (2017) in Tigray and Bikila *et al.*, (2016) in Borana, North and Southern Ethiopia, have reported a significantly higher AGB carbon stock in exclosures than open grazing land. Another study by Mekuria and Yami, (2013) also displayed higher AGB in exclosures when compared to the adjacent communal grazing lands.

More importantly, this study demonstrated that pronounced woody biomass carbon can be stocked in the long-term. Generally, excluding degraded landscapes from free access of domestic animals and humans might bring an overall ecological restoration to the sites. Thus, such a restoration mechanism might contribute to the efforts of mitigating climate change in developing countries. A study by Witt *et al.*, (2011) indicated a pronounced woody biomass carbon stock and significant ecological change following long-term grazing exclusion.

CONCLUSION

This study evaluated the influence of different ages of exclosure and adjacent open grazing land on woody vegetation structure, composition, and aboveground biomass carbon stock in the central dry lowland of Ethiopia. The results demonstrate that a considerable amount of woody species was restored due to the exclusion of open grazing land for rehabilitation purposes. Furthermore, woody species structure i.e., basal area, tree density, and composition were significantly influenced by age of exclosures. Excluding grazing animals and human interferences from accessing severely degraded lands for long period resulted in an approximate doubling of the tree density, standing basal area, species diversity, aboveground biomass, and carbon stock relative to grazed areas. The significantly higher aboveground biomass and aboveground biomass carbon stock clearly showed that degraded land restoration strategies through exclosure can sequester a large quantity of atmospheric carbon dioxide. To comprehend more on the impact of area exclosures on carbon stock, further investigation on belowground biomass and soil carbon stock is suggested.

LIST OF ABBREVIATIONS

AGB	=	Aboveground Biomass
BGB	=	Belowground biomass
H'	=	Shannon-Wiener diversity index
BA	=	Basal Area
dbh	=	Diameter at breast height
HSD	=	Honest Significant Difference

IVI	=	Importance Value Index
RA	=	Relative Abundance
RD	=	Relative Dominance
RF	=	Relative Frequency

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

FUNDING

Not applicable.

CONFLICT OF INTEREST

The authors declare that they have no any conflict of interest.

ACKNOWLEDGEMENTS

Debre Birhan University, Ethiopia is duly acknowledged for the assistance of this study.

REFERENCES

- Abaker, WE, Berninger, F, Saiz, G, Braojos, V & Starr, M (2016) Contribution of *Acacia senegal* to biomass and soil carbon in plantations of varying age in Sudan. *For Ecol Manage*, 368, 71-80. [<http://dx.doi.org/10.1016/j.foreco.2016.03.003>]
- Elsevier, BV, Abebe, T, Feyssa, DH & Kissi, E (2014) Area Exclosure as a Strategy to Restore Soil Fertility Status in Degraded Land in Southern Ethiopia. *Journal of Biological and Chemical Research*, 31(1), 482-94.
- Abiyu, A, Lemenih, M, Gratzner, G, Aerts, R, Teketay, D & Glatzel, G (2014) Status of Native Woody Species Diversity and Soil Characteristics in an Exclosure and in Plantations of *Eucalyptus globulus* and *Cupressus lusitanica* in Northern Ethiopia. *Mountain Research and Development*, 31(2), 144-52.
- Aerts, R, Nyssen, J & Haile, M (2011) On the difference between "exclosures" and "enclosures" in ecology and the environment. *Journal of Arid Environments*, 73(8), 762-3.
- Appanah, S, Shono, K & Durst, PB Restoration of forests and degraded lands in Southeast Asia. *Unasyuva*, 66(245), 52-63.
- Berisso, T (1995) Deforestation and Environmental Degradation in Ethiopia: The Case of Jam Jam Province. *Northeast African Studies*, 2(2 (New Series)), 139-55.
- Bikila, NG, Tessema, ZK & Abule, EG (2016) Carbon sequestration potentials of semi-arid rangelands under traditional management practices in Borana, Southern Ethiopia. *Agriculture, Ecosystems and Environment*, 223(2 (New Series)), 108-14. [<http://dx.doi.org/10.1016/j.jaridenv.2009.01.006>]
- Birhane, E, Aregawi, K & Giday, K (2017) Changes in arbuscular mycorrhizal fungi spore density and root colonization of woody plants in response to exclosure age and slope position in the highlands of Tigray, Northern Ethiopia. *J Arid Environ*, 142, 1-10. [Elsevier Ltd.]. [<http://dx.doi.org/10.1016/j.jaridenv.2017.03.002>]
- Birhane, E, Kuyper, TW, Sterck, FJ & Bongers, F (2010) Arbuscular mycorrhizal associations in *Boswellia papyrifera* (frankincense-tree) dominated dry deciduous woodlands of Northern Ethiopia. *For Ecol Manage*, 260(12), 2160-9. [Elsevier B.V.]. [<http://dx.doi.org/10.1016/j.foreco.2010.09.010>]

- Birhane, E, Teketay, D & Barklund, P (2006) Actual and potential contribution of exclosures to enhance biodiversity of woody species in the drylands of Eastern Tigray Actual and potential contribution of exclosures to enhance biodiversity of woody species in the drylands of Eastern Tigray. *Journal of the Drylands*, 1(2), 134-47.
- Birhane, E, Teketay, D & Barklund, P (2007) East African Journal of Sciences (2007) Enclosures to Enhance Woody Species Diversity in The Dry Lands of Eastern Tigray. *East African Journal of Sciences*, 1, 136-47. [http://dx.doi.org/10.4314/eajsci.v1i2.40352]
- Bishaw, B (2001) Deforestation and Land Degredation in the Ethiopian Highlands: A Strategy for Physical Recovery. *Northeast Afr Stud*, 8(1), 7-25. [http://dx.doi.org/10.1353/nas.2005.0014]
- Bizuayehu, S & Tefera, B (2008) *Assessment on Socioeconomics Aspects of Area Enclosures in North Shewa Zone: The case of Kewote and Basona Worena woredas*, 1-15.
- Chen, Y, Li, Y, Zhao, X, Awada, T, Shang, W & Han, J (2012) Effects of grazing exclusion on soil properties and on ecosystem carbon and nitrogen storage in a sandy rangeland of Inner Mongolia, northern China. *Environ Manage*, 50(4), 622-32. [http://dx.doi.org/10.1007/s00267-012-9919-1] [PMID: 22829221]
- CSA (Central Statistical Agency Ethiopia). (2013). *Population Projection of Ethiopia for All Regions At Wereda Level from 2014 – 2017 Federal Democratic Republic of Ethiopia Central Statistical Agency*
- Descheemaeker, K, Muys, B, Nyssen, J, Poesen, J, Raes, D, Haile, M & Deckers, J (2006) Litter production and organic matter accumulation in exclosures of the Tigray highlands, Ethiopia. *For Ecol Manage*, 233(1), 21-35. a [http://dx.doi.org/10.1016/j.foreco.2006.05.061]
- Descheemaeker, K, Nyssen, J, Poesen, J, Haile, M, Muys, B, Raes, D, Moeyersons, J & Deckers, J (2006) Soil and Water Conservation Through Forest Restoration in Exclosures of the Tigray Highlands. *Journal of the Drylands*, 1(2), 118-33. b
- Dessie, G & Christiansson, C (2008) Forest decline and its causes in the south-central rift valley of Ethiopia: human impact over a one hundred year perspective. *Ambio*, 37(4), 263-71. [http://dx.doi.org/10.1579/0044-7447(2008)37[263:FDAICI]2.0.CO;2] [PMID: 18686505]
- Edwards, S, Tadesse, M, Hedberg, I (1995). *Flora of Ethiopia and Eritrea: Canellaceae to Euphorbiaceae The National Herbarium*. Addis Ababa University.
- Etter, H (2016) *Land Degradation: An Economic Perspective*. Land Restoration Elsevier Inc..
- FAO. (2015). *Global Forest Resources Assessment (FRA)-Country Report*.
- Feyisa, K, Beyene, S, Angassa, A, Said, MY & De Leeuw, J (2017) Effects of enclosure management on carbon sequestration, soil properties and vegetation attributes in East African rangelands. *Catena*, 159, 9-19. [Elsevier.]. [http://dx.doi.org/10.1016/j.catena.2017.08.002]
- Gebremedihin, KM, Birhane, E, Tadesse, T & Gbrehahid, H (2018) Restoration of Degraded Drylands Through Exclosures Enhancing Woody Species Diversity and Soil Nutrients in the Highlands of Tigray, Northern Ethiopia. *Nature Conservation Research*, 3(1), 1-20. [http://dx.doi.org/10.24189/ncr.2018.001]
- Giday, K, Eshete, G, Barklund, P, Aertsen, W & Muys, B (2013) Wood biomass functions for Acacia abyssinica trees and shrubs and implications for provision of ecosystem services in a community managed enclosure in Tigray, Ethiopia. *J Arid Environ*, 94, 80-6. [Elsevier Ltd.]. [http://dx.doi.org/10.1016/j.jaridenv.2013.03.001]
- Girmay, G, Singh, BR, Mitiku, H, Borresen, T & Lal, R (2008) Carbon stocks in Ethiopian soils in relation to land use and soil management. *Land Degrad Dev*, 19(4), 351-67. [http://dx.doi.org/10.1002/ldr.844]
- Haftom, H, Girmay, T, Emiru, B, Haftu, A & Meseret, H (2019) Impact of farm enclosure on woody species abundance and carbon stock in Tigray, Northern Ethiopia. *Cogent Environ Sci*, 5(1), 1-10. [Cogent.]. [http://dx.doi.org/10.1080/23311843.2019.1656444]
- Haile, M, Herweg, K & Stillhardt, B (2006) *Sustainable Land Management – A New Approach to Soil and Water Conservation in Ethiopia*. Mekelle University.
- Hedberg, I, Edwards, S (1989). *Flora of Ethiopia: Pittosporaceae to Araliaceae The National Herbarium*. Addis Ababa University.
- Hedberg, I, Edwards, S, Nemomissa, S (2003). *Flora of Ethiopia and Eritrea: Apiaceae to Dipsacaceae The National Herbarium*. Addis Ababa University.
- Hedberg, I, Kelbessa, E, Edwards, S, Demissew, S, Persson, E (2006). *Flora of Ethiopia and Eritrea: Gentianaceae to Cyclocheilaceae The National Herbarium, Biology DeThe National Herbarium*. Addis Ababa University.
- Hurni, H, Solomon, A, Amare, B, Berhanu, D, Ludi, E, Portner, B, Birru, Y & Gete, Z (2010) Land degradation and sustainable land management in the highlands of Ethiopia. *Global change and sustainable development: a synthesis of regional experiences from research partnerships Perspectives of the Swiss National Centre of Competence in Research (NCCR) North-South*, University of Bern 187-207.
- Ibrahim, MA (2016) Impact of Enclosure on Plant Species Composition and Biomass Production in Ewa Woreda of Afar Region State, Ethiopia. *Journal of Biodiversity & Endangered Species*, 4(1), 1-4.
- Intergovernmental Panel on Climate Change (IPCC). (2006). *IPCC Guidelines for National Greenhouse Gas Inventories The Intergovernmental Panel on Climate Change (IPCC)*
- Kent, M (2012) *Vegetation Description and Data Analysis: A Practical Approach* [http://books.google.com/books?id=xHnXf0wHdQC&pgis=1]
- Lemenih, M (2006) Expediting ecological restoration with the help of foster tree plantations in Ethiopia. *journal of the drylands*, 1(1), 72-84.
- Lemenih, M & Kassa, H (2014) Re-greening Ethiopia: History, challenges and lessons. *Forests*, 5(8), 1896-909. [http://dx.doi.org/10.3390/f5081896]
- Li, Y, Zhou, X, Brandle, JR, Zhang, T, Chen, Y & Han, J (2012) Temporal progress in improving carbon and nitrogen storage by grazing enclosure practice in a degraded land area of China ' s Horqin Sandy Grassland. *Agric Ecosyst Environ*, 159, 55-61. [Elsevier B.V.]. [http://dx.doi.org/10.1016/j.agee.2012.06.024]
- Magurran, AE (2004) *Measuring Biological Diversity*. Blackwell Science Ltd..
- Meaza, H, Frankl, A, Poesen, J, Zenebe, A, Deckers, J, Van Eetvelde, V, Demissie, B, Ghebreyohannes, T & Nyssen, J (2017) Natural resource opportunities and challenges for rural development in marginal grabens e The state of the art with implications for the Rift Valley system in Ethiopia. *J Arid Environ*, 147, 1-16. [Elsevier Ltd.]. [http://dx.doi.org/10.1016/j.jaridenv.2017.08.003]
- Mekuria, W & Aynekulu, E (2013) Exclosure land management for restoration of the soils in degraded communal grazing lands in northern ethiopia. *Land Degrad Dev*, 24(6), 528-38. [http://dx.doi.org/10.1002/ldr.1146]
- Mekuria, W, Langan, S, Johnston, R, Belay, B, Amare, D, Gashaw, T, Desta, G, Noble, A & Wale, A (2015) Restoring aboveground carbon and biodiversity: A case study from the Nile basin, Ethiopia. *Forest Sci Technol*, 11(2), 86-96. [http://dx.doi.org/10.1080/21580103.2014.966862]
- Mekuria, W, Langan, S, Noble, A & Johnston, R (2017) Soil Restoration after seven Years of Exclosure Management in Northwestern Ethiopia. *Land Degrad Dev*, 28(4), 1287-97.

[<http://dx.doi.org/10.1002/ldr.2527>]

Mekuria, W, Wondie, M, Amare, T, Wubet, A, Feyisa, T & Yitaferu, B (2018) Restoration of degraded landscapes for ecosystem services in North-Western Ethiopia. *Heliyon*, 4(8)e00764

[<http://dx.doi.org/10.1016/j.heliyon.2018.e00764>] [PMID: 30186984]

Mekuria, W & Yami, M (2013) Changes in woody species composition following establishing exclosures on grazing lands in the lowlands of Northern Ethiopia. *Afr J Environ Sci Technol*, 7(January), 30-40.

Mengistu, T, Teketay, D, Hulten, H & Yemshaw, Y (2005) The role of exclosures in the recovery of woody vegetation in degraded dryland hillsides of central and northern Ethiopia. *J Arid Environ*, 60(2), 259-81.

[<http://dx.doi.org/10.1016/j.jaridenv.2004.03.014>]

Nair, PKR, Nair, VD, Kumar, BM & Haile, SG (2009) Soil carbon sequestration in tropical agroforestry systems : A feasibility appraisal §. *Environ Sci Policy*, 12, 1099-111.

[<http://dx.doi.org/10.1016/j.envsci.2009.01.010>]

Negussie, A, Aerts, R, Gebrehiwot, K & Muys, B (2008) *Seedling mortality causes recruitment limitation of Boswellia papyrifera in northern Ethiopia*, 72, 378-83.

Newton, A (2007) *Forest Ecology and Conservation: A Handbook of Techniques*. Oxford University Press.

[<http://dx.doi.org/10.1093/acprof:oso/9780198567448.001.0001>]

Nyssen, J, Frankl, A, Zenebe, A, Deckers, J & Poesen, J (2015) Land Management in the Northern Ethiopian Highlands: Local and Global Perspectives; Past, Present and Future. *Land Degrad Dev*, 26(7), 759-64.

[<http://dx.doi.org/10.1002/ldr.2336>]

Nyssen, J, Naudts, J, De Geyndt, K, Haile, M, Poesen, J, Moeyersons, J & Deckers, J (2008) Soils and land use in the Tigray Highlands (Northern Ethiopia). *Land Degrad Dev*, 19(3), 257-74. a

[<http://dx.doi.org/10.1002/ldr.840>]

Nyssen, J, Temesgen, H, Lemenih, M, Zenebe, A, Haregeweyn, N & Haile, M (2008) *Spatial and temporal variation of soil organic carbon stocks in a lake retreat area of the Ethiopian Rift Valley* 261-8.

Paris, S (1986) *Reconnaissance Soil Survey and Land Evaluation for Irrigation Purposes of an area near Robit (Shewa)*. National Water Resource Commission, Water Resource Development Authority of Ethiopia.

Qasim, S, Gul, S, Shah, MH, Hussain, F, Ahmad, S, Islam, M, Rehman, G, Yaqoob, M & Shah, SQ (2017) Influence of grazing exclosure on vegetation biomass and soil quality. *International Soil and Water Conservation Research*, 5(1), 62-8. [Elsevier B.V.]

[<http://dx.doi.org/10.1016/j.iswcr.2017.01.004>]

Ruiz-Jaen, MC & Aide, TM (2005) Restoration success: How is it being measured? *Restor Ecol*, 13(3), 569-77.

[<http://dx.doi.org/10.1111/j.1526-100X.2005.00072.x>]

Shiferaw, A, Hurni, H & Zeleke, G (2013) *Long-term changes in soil-based ecological services at three sites in Ethiopia*, 5(August), 172-80.

Shimelse, S, Bekele, T & Nemomissa, S (2017) Effect of Exclosure Age on Carbon Sequestration Potential of Restorations in Tigray Region, N. Ethiopia. *American Journal of Biological and Environmental Statistics*, 3(4), 65-80.

[<http://dx.doi.org/10.11648/j.ajbes.20170304.14>]

Solomon, N, Hishe, H, Annang, T, Pabi, O, Asante, IK & Birhane, E (2018) Forest cover change, key drivers and community perception in Wujig Mahgo Waren forest of northern Ethiopia. *Land (Basel)*, 7(1)

[<http://dx.doi.org/10.3390/land7010032>]

Taddese, G (2001) Land degradation: A challenge to Ethiopia. *Environ Manage*, 27(6), 815-24.

[<http://dx.doi.org/10.1007/s002670010190>] [PMID: 11393316]

Tefera, M, Chernet, T & Haro, W (1996) *Geological Map of Ethiopia: Topographic base map, scale 1:2,000,000 2 ed Geological Survey of Ethiopia*

Teketay, D, Kashe, K, Madome, J, Kabelo, M, Neelo, J, Mmusi, M & Masamba, W (2018) Enhancement of diversity, stand structure and regeneration of woody species through area exclosure: The case of a mopane woodland in northern Botswana. *Ecol Process*, 7(1), 1-15. [Ecological Processes.]

[<http://dx.doi.org/10.1186/s13717-018-0116-x>]

Tesfay, F, Kibret, K, Gebrekirstos, A & Hadigu, KM (2020) Changes in selected soil properties across a chronosequence of exclosures in the central dry lowlands of Ethiopia. *Eurasian J Soil Sci*, 9(2), 173-85.

[<http://dx.doi.org/10.18393/ejss.707667>]

Tetemke, BA, Birhane, E, Rannestad, MM & Eid, T (2019) Allometric models for predicting aboveground biomass of trees in the dry afro-montane forests of Northern Ethiopia. *Forests*, 10(12), 1-15.

[<http://dx.doi.org/10.3390/f10121114>]

Tolera, M, Asfaw, Z, Lemenih, M & Karlton, E (2008) Woody species diversity in a changing landscape in the south-central highlands of Ethiopia. *Agric Ecosyst Environ*, 128(1-2), 52-8.

[<http://dx.doi.org/10.1016/j.agee.2008.05.001>]

Witt, GB, Noël, MV, Bird, MI, Beeton, RJS & Menzies, NW (2011) Carbon sequestration and biodiversity restoration potential of semi-arid mulga lands of Australia interpreted from long-term grazing exclosures. *Agric Ecosyst Environ*, 141(1-2), 108-18. [Elsevier B.V.]

[<http://dx.doi.org/10.1016/j.agee.2011.02.020>]

Yayneshet, T (2011) Restoration of Degraded Semi-Arid Communal Grazing Land Vegetation Using the Exclosure Model. *International Journal of Water Resources and Arid Environment*, 1(5), 382-6.

Yayneshet, T, Eik, LO & Moe, SR (2008) Feeding Acacia etbaica and Dichrostachys cinerea fruits to smallholder goats in northern Ethiopia improves their performance during the dry season. *Livest Sci*, 119(1-3), 31-41. [Elsevier B.V.]

[<http://dx.doi.org/10.1016/j.livsci.2008.02.007>]

Yimer, F, Alemu, G & Abdelkadir, A (2015) Soil property variations in relation to exclosure and open grazing land use types in the Central Rift Valley area of Ethiopia. *Environmental Systems Research*, 4(1)

[<http://dx.doi.org/10.1186/s40068-015-0041-2>]

Yirdaw, E & Monge, A (2018) *Reconsidering what exclosure and exclosure mean in restoration ecology*, 26(1), 45-7.