Received: 9 March 2023 | Revised: 14 May 2023 | Accepted: 19 May 2023

DOI: 10.1002/ldr.4781

RESEARCH ARTICLE

WILEY

Natural regeneration offers an effective way for large-scale restoration of degraded lands in Tigray, Ethiopia

Haileselassie Ghebremariam Araya[1] | Oliver Vivian Wasonga[1] | Stephen Mureithi[1] | Emiru Birhane[2]

[1]Department of Land Resources Management and Agricultural Technology (LARMAT), University of Nairobi, Nairobi, Kenya

[2]Department of Land Resources Management and Environmental Protection (LaRMEP), Mekelle University, Mekelle, Ethiopia

Correspondence
Haileselassie Ghebremariam Araya, Department of Land Resources Management and Agricultural Technology (LARMAT), University of Nairobi, P. O. Box 29053–00625, Nairobi, Kenya.
Email: hailish746990@gmail.com

Funding information
Danish International Development Agency

Abstract

Land rehabilitation through exclosures has been recognized as a promising practice in the restoration of degraded drylands. This study evaluated woody species density, diversity, cover, and biomass production from three regeneration approaches (EMTs): (1) Naturally Regenerated (ENR) exclosures, (2) exclosures with Soil and Water Conservation Structures (ECNR), and (3) those enriched with exotic and local plant species in addition to SWC structures (ECP) among which empirical evidence of comparisons are lacking for appropriate decision making of which restoration strategy to promote. Primary data were collected from a total of 72 study plots located across transects laid within exclosures and in adjacent grazing areas with similar ecological condition. Interview with 331 households and focus groups was used to further understand the effects. Regression analysis revealed that the mean difference in herbaceous and canopy cover, herbaceous and woody biomass, and woody species density and diversity of the three EMTs was statistically significantly higher than in the adjacent open grazing areas. Moreover, herbaceous biomass in ECP differed significantly from that of ECNR. The results indicated that ENR and ECP equally enhanced the selected vegetation parameters. This is predominantly attributed to the comparable responsiveness of many degraded areas to natural regeneration as they do to active regeneration approaches. Implementation of natural regeneration is suitable for immediate recruitment of strategy in terms of resources, time, and meeting objectives before decisions are made for assisted models of exclosure that require massive campaigns to construct soil and water conservation structures and huge seedling production in the dryland areas.

KEYWORDS
degraded lands, exclosure management type, landscape-regeneration, restoration

1 | INTRODUCTION

Land degradation (LD) is the temporary or permanent decline in the productive *capacity* of the land, and the diminution of the productive *potential*, including its major land uses, its farming systems, and its value as an economic resource (Stocking, 2001). LD is a chronic challenge causing annual global loss of $6.3–10.6 trillion (Cornell et al., 2016). The universal degradation losses are related to biological productivity, economic sustainability, and ecosystem services (Gilbey et al., 2019). Sadly, an estimated 23% of the world's land area is affected by LD (Stavi & Lal, 2015), and the associated costs affect every individual (ELD Initiative, 2015). The underlying drivers of LD include unsustainable forestry practices, global consumption patterns, and climate change (Sutton et al., 2016; van der Esch et al., 2017). Other contributory factors are urbanization, infrastructure development, and extractive industries, which are often associated with landscape alterations (van der Esch et al., 2017).

LD is a leading problem in sub-Saharan Africa threatening the lives of millions of inhabitants (Blay et al., 2004) through diminishing crop yield (Zingore et al., 2010) and forest production (Blay et al., 2004). In Ethiopia, soil and environmental degradation due to the conversion of forest and communal lands into crops and settlements (Ellen, 2011; Mebrat, 2015) to accommodate population growth (Blay et al., 2004) has been a pressing challenge. The shrinkage of historical forest due to conversion into cultivated lands and settlements and reduction of communal grazing lands mainly due to alteration into exclosures (Yayneshet, 2010) facilitated further depletion of open grazed lands through overutilization (Blay et al., 2004). More importantly, the LD problems are wicked and linked to many other global and local challenges including food insecurity, poverty, and environmental degradation. LD remains to be Ethiopia's consequential and incessant complexity (Taddese, 2001) impeding Agriculture Development Lead Industrialization (ADLI) and Climate Resilient Green Economy (Federal Democratic Republic of Ethiopia, 2012). Therefore, reversing the LD was not an option but a compulsory errand to solve numerous and interlinked tight spots. The government of Ethiopia, therefore, initiated major rehabilitation of degraded drylands (Kebrom, 2001) three decades ago, which continued in a high scale implementation (Gebremichael & Waters-Bayer, 2007) in line with the Bonn Challenge and other initiatives (Birhane et al., 2017). Exclosure of the grazing lands has been a national program with a high level of execution in Tigray (Jabbar et al., 2000) where rehabilitation efforts were reported to have been started as early as the 1970s (Munro et al., 2019).

Exclosure program started in the 1980s in coincidence with the extensive soil conservation movements in Ethiopia (Nedessa et al., 2005) which then continued massively with varied scales based on the capability of the regional states to mobilize their human resources to engage in free and paid labor. This practice has been extensively exercised since 1991 in Tigray (Bainbridge, 2017) in which more than 1.5 million hectares of land have been rehabilitated in a period of over 20 years, benefiting about 2 million people (Bainbridge, 2017; Lemenih & Kassa, 2014). Uncontrolled human interference and agricultural expansion inhibited Tigray region to have any forest cover before 1994 with only scattered forests around churches and remote places which rarely exceeded 9% of the total land area (Wisborg et al., 2000).

Exclosure, as a rehabilitation program, generally falls into two broad categories: Natural and assisted (Mebrat, 2015). The latter has two levels and is an active restoration in which target landscapes can be enriched with seedlings and seeds or just left to naturally regenerate after being furnished only with soil and water conservation structures depending on the characteristics of the LD. So, three definite levels of exclosure management types (EMTs) were identified that are anticipated to diverge in ecosystem functions and processes after the successful achievement of restoration objectives.

Natural Regeneration Exclosure (ENR) is a method in which a previous communal grazing land is protected from human and animal interventions (Ellen, 2011; Nedessa et al., 2005) to establish a native vegetation from existing seed bank and oppressed plant species (Mebrat, 2015; Murthy et al., 2002; van Ulft, 2004). Assisted regeneration (AR) of degraded areas, on the other hand, is established on similar communal grazing lands with main management schemes solely for soil and water conservation structures or can be followed by enrichment with planting and seeding. It can involve commercial tree planting and ecological restoration through growing diverse native species that have been identified to dominate previously degraded sites. Active restoration interventions of highly degraded areas can recover biodiversity and ecosystem services (Brancalion et al., 2016; Latawiec et al., 2016). It aims to accelerate natural regeneration and development processes when the spontaneous establishment of trees is insufficient to create conditions for successful native plant regeneration and forest development (Hardwick & Elliott, 2016; Holl & Aide, 2011). The high cost of active restoration projects (Birhane et al., 2017) than natural regeneration is a very notable constraint, and therefore, financial capacity limits its large-scale implementation.

To the best of our knowledge, the current study is the first to compare assisted and natural regeneration in Tigray using key vegetation parameters. Therefore, empirical evidence of whether the level of degradation can be fully or partially suited to natural regeneration projects or active restoration approaches is still lacking. The existing sustainable land management projects which were established spontaneously provided tremendous research opportunities to deepen our understanding of restoration options via natural regeneration but they seem to remain underutilized (Uriarte & Chazdon, 2016). Pocket areas of natural regeneration exist within the assisted restoration projects in the drylands of the Tigray Region. It was proved that Sustainable Land Management Program (SLMP) was established without prior consideration of determinant factors. It could serve as a basis for characterizing how successful are the natural and assisted restoration schemes. In general, the suitability and likelihood success of natural regeneration as a restoration mechanism is less explored and comparisons are rarely made (Brancalion et al., 2016; Gilman et al., 2016). Previous studies on exclosures in Ethiopia, and the Tigray region in particular, failed to consider the variation of these exclosure management types and have focused mainly on the highlands (Descheemaeker et al., 2006). Recommendations emphasized that ecological achievements of exclosures require more comprehensive (Mekuria et al., 2017) and rigorous research (Balana et al., 2012) that should consider different restoration approaches. This research, therefore, focused on the impacts of EMTs on key vegetation parameters in the lowlands of Tigray wherein studies were limited and degradation is high. The objectives of this study were, therefore, to explore the effects of EMTs on selected vegetation parameters in the drylands of Tigray to help shaping policy on the restoration efforts on dry lowlands of the region and beyond. We hypothesized that exclosure management types will improve vegetation attributes of degraded areas in the order of ECP > ECNR>ENR in density, diversity, biomass, and cover.

2 | MATERIALS AND METHODS

2.1 | Study area

The research was conducted in the Tanqua-Abergele district of Tigray, Northern Ethiopia during 2019–2020 (Figure 1). Tanqua-Abergele is found in the lowland zones of Tigray at an altitude between 932 and 2394 masl. According to the land administration desk of the district, the total land area is estimated at 144564 ha with Land Use/Land Cover (LULC) categories of 45,206 ha (arable), 2433 ha (pasture), and 17,382 ha (exclosures). The rest 79,543 ha is composed of mountains, grazing, settlement areas, and other miscellaneous lands. The district is administratively organized into 20 villages and 80 hamlets. The average annual rainfall varies between 580 and 750 mm, typically erratic and with poor spatial and temporal distribution. The average annual temperature ranges between 18 and 26°C. The climate is favorable for major lowland crops like sorghum, maize, teff, finger millet, sesame, groundnut, and some spices and vegetables. Fruits like orange, mango, lemon, tangerine, banana, and guava grow well. The district owns 268,266 livestock head counts. Forty to sixty percent of the people make a living on livestock under a dominant mixed production system (Nyssen et al., 2009) in which livestock either seasonally or daily moved to search feed and water. As the district is exceptionally highly populated with livestock, an export-oriented slaughterhouse has been established by Abergele International Livestock Development PLC to utilize this endowment through export. The estimated total human inhabitants are 92,888.

2.2 | Site selection

Tanqua-Abergele district was systematically selected from projects under SLMP in Tigray. The SLMP project districts in the Tigray region were grouped by agroecology into Low and highlands. Tanqua Abergele was randomly picked from the lowland districts within SLMP. The villages were categorized into two agroecological zones (AEZ) (Dry lowland, Dry midland). In each AEZ, villages were ranked based on the types and area coverage of exclosures. From each of the two dominant AEZs of the district, five villages were systematically selected (Figure 1).

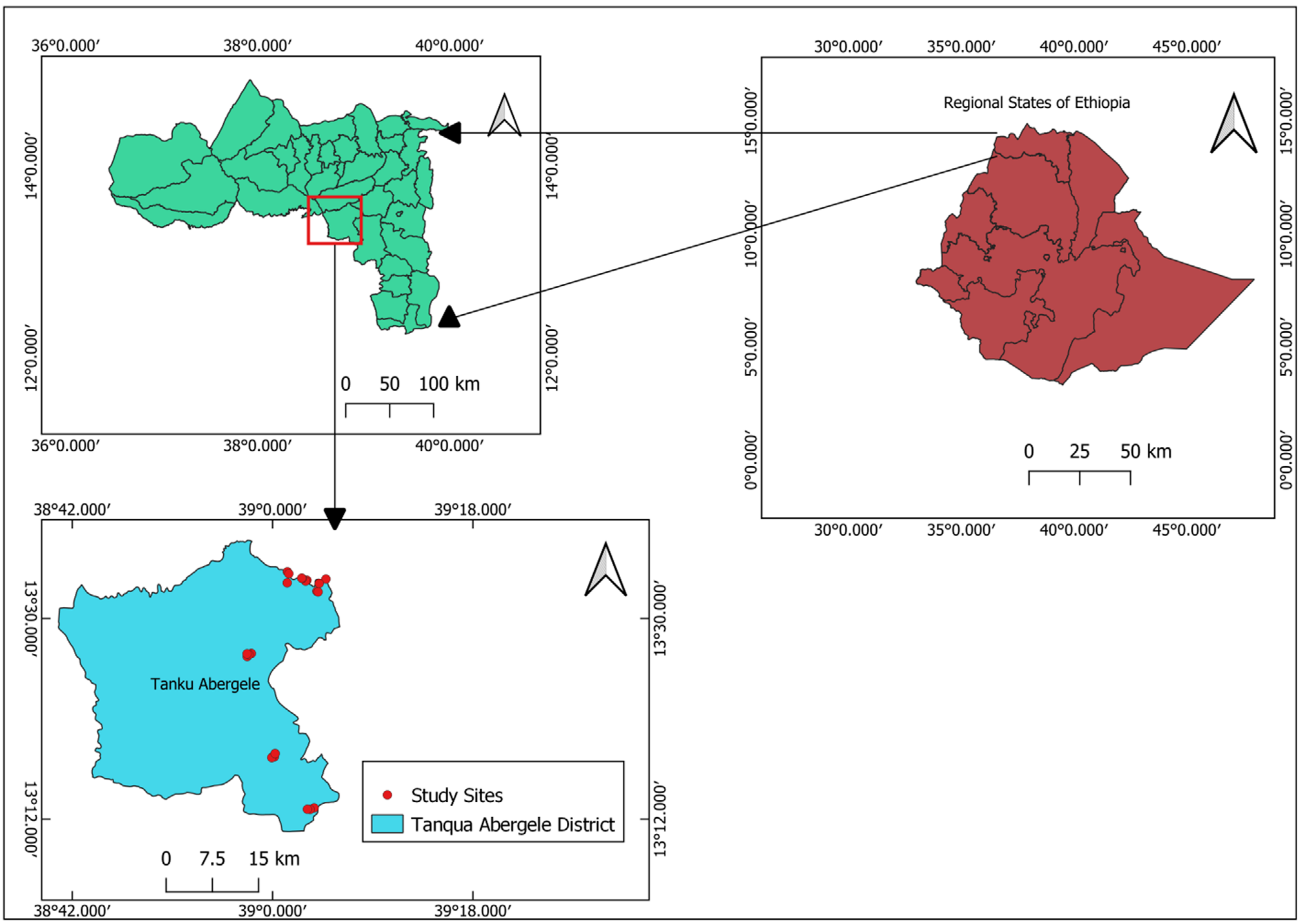

FIGURE 1 Map of Tanqua Abergele district (the study area) and location of study sites (map developed using QGIS 3.28). [Colour figure can be viewed at wileyonlinelibrary.com]

2.3 | Experimental layout and vegetation sampling

In the five selected villages, a total of 29 exclosures were sorted into three management types: vis-à-vis (a) Natural Regeneration (ENR), (b) exclosures treated only with different soil and water conservation structures (ECNR), and (c) exclosures treated with soil and water conservation structures and re-vegetated with exotic and local plants (ECP). Three exclosures, aged 8–10 years, were randomly selected from each category fulfilling the above criteria in each AEZ making a total of 18 study sites (2 agroecology*3 categories of exclosures*3 replications) organized in a Completely Randomized Block Design (RCBD) with four treatments and three replications. In each exclosure, one diagonal transect was laid along which three suitable plots of 20×20 m were established (18 transects*3 plots = 54 study plots). Each exclosure was paired with adjacent open grazing land (6*3 = 18 plots). In each plot, 1×1 m sub-plots were also nested at the four corners and at the center. Samples for woody and herbaceous vegetation parameters were taken from the plots and sub-plots, respectively. An interview was conducted with 331 household heads in the five villages to rate the EMTs from 1 to 3, 1 being the lowest and 3 being the highest rankings in terms of a better restoration capacity. Similarly, a focus group discussion and key informant interviews were conducted to understand their views about the EMTs.

2.4 | Determination of vegetation attributes

The herbaceous cover was directly estimated using line intercept methods (Jiapaer et al., 2011; Wasonga et al., 2009). The woody canopy cover was estimated from 1383 woody plant species found within 72 study plots (Coulloudon et al., 1996). Estimation of woody plant species density was done by a plot (Raunkiaer, 1934) in a carefully designed field layout. While woody species diversity was determined using the Shannon diversity index (Shannon, 1948) which was log-transformed before regression analysis was employed. Above-ground herbaceous biomass production was estimated in each sample plot during the growing and dry seasons using the harvesting method (t'Mannetje & Jones, 2000). Biomass production for trees and shrubs was estimated from plant attributes using recently developed models for exclosures in Tigray (Ubuy et al., 2018). Botanical species names were recorded by asking knowledgeable farmers. Later, the English names and scientific names were found in various publications, books, and online plant identification apps to interpret images taken during data collection.

2.5 | Data analysis

Data were analyzed using Stata (StataCorp, 2017) version 15. All data were subjected to Shapiro–Wilk test for normality before analysis. Using regression analysis comparison of mean variation was conducted to see if there was a significant difference among exclosure management types in herbaceous cover, canopy cover, woody plant species density, diversity, and above-ground biomass production for herbs and woody plants. A standard multiple regression model (1) was used to test the dependent variables species density, diversity, cover, and biomass across the exclosure management types.

$$\hat{\mu}_i = E(Y_i) = \hat{\beta}_0 + \hat{\beta}_1 X_1 + \hat{\beta}_2 X_2 + \hat{\beta}_3 X_3 \tag{1}$$

where i = {G for Grazing, ENR for natural regeneration, ECNR for soil and water conservation only and ECP for soil, water conservation, and enrichment}.

So, if an observation corresponds to management type which is Grazing (Control), then, $X_1 = X_2 = X_3 = 0$. Then, the estimate $\hat{\beta}_0$ corresponds to the estimated mean response for Grazing only. In a similar way, if the observation corresponds to ENR; $X_1 = 1$, $X_2 = 0$, $X_3 = 0$. $\hat{\beta}_1$ would represent the difference in the estimated mean response between ENR and Grazing (i.e., $\hat{\beta}_{ENR} - \hat{\beta}_{Grazing}$), $\hat{\beta}_2$ would represent the difference in the estimated mean response between ECNR and Grazing ($\hat{\beta}_{ECNR} - \hat{\beta}_{Grazing}$), and $\hat{\beta}_3$ would represent the difference in estimated mean response between ECP and Grazing ($\hat{\beta}_{ECP} - \hat{\beta}_{Grazing}$). This contrasted the three EMTs with the adjacent grazing lands (control) designated as R_{S1i}, R_{S2i}, R_{S3i}, (Table 1), R_{S8i}, R_{S9i}, R_{S10i} (Table 2), R_{S15i}, R_{S16i}, and R_{S17i} (Table 3). While comparisons of ENR versus ECNR and ECNR versus ECP were made by applying forward coding (R_{F4i}, R_{F5i} [-Table 1], R_{F11i},, R_{F12i} [Table 2] and R_{F18i} and R_{F19i} [Table 3]) in which mean differences were calculated as $\hat{\beta}_{ENR} - \hat{\beta}_{ECNR}$ and $\hat{\beta}_{ECNR} - \hat{\beta}_{ECP}$.

In order to accurately test our hypothesis regarding the management approaches, we conducted successive comparison of levels of exclosure management approaches (Equations 2 and 3):

$$R_{Hi} = \hat{\mu}_G - \left(\frac{\hat{\mu}_{ENR} + \hat{\mu}_{ECNR} + \hat{\mu}_{ECP}}{3}\right), \tag{2}$$

$$R_{Hi} = \hat{\mu}_{ENR} - \left(\frac{\hat{\mu}_{ECNR} + \hat{\mu}_{ECP}}{2}\right). \tag{3}$$

Helmert contrast helps obtain useful comparisons of the mean responses of the EMTs, and the resulting estimated coefficients (R_{H6i}, R_{H13i}, and R_{H20i}; Tables 1, 2 and 3, respectively), would represent the difference between the mean responses for Grazing and the 'mean of the mean' response for the ENR, ECNR, and ECP group. R_{H7i}, R_{H14i}, and R_{H21i} were used in the same way to evaluate mean differences. Mean differences at each level were compared to the average of the consecutive levels. The first comparison was made between grazing (control) and the average of the means of the three levels of EMTs. It gave concrete evidence if exclosure in general was feasible restoration strategy. Then we compared ENR with the means of ECNR and ECP. This enabled us compare if natural regeneration was outperformed by assisted exclosure management. The responses from individual household interviews were also analyzed using rating scale

TABLE 1 Comparison of woody plant species density (Plants/ha) and biodiversity (log-Shannon diversity index) among exclosure management types in Tanqua-Abergele district (Obs = 72).

	Woody plant species density			Log-Shannon diversity index		
*MD	$\beta \pm$ SE	T	p	$\beta \pm$ SE	T	p
R_{S1i}	785.67 (150.90)	5.21	0.000	0.34002 (0.1195)	2.84	0.01
R_{S2i}	630.17 (150.90)	4.18	0.000	0.28837 (0.1195)	2.41	0.026
R_{S3i}	440.61 (150.90)	2.92	0.005	0.24383 (0.1195)	2.04	0.055
R_{F4i}	155.50 (150.90)	1.03	0.306	0.05175 (0.1195)	0.43	0.67
R_{F5i}	189.56 (150.90)	1.26	0.213	0.04440 (0.1195)	0.37	0.714
R_{H6i}	−618.81 (123.21)	−5.02	0.000	−0.29071 (0.0976)	−2.98	0.007
R_{H7i}	250.28 (130.68)	1.92	0.060	0.07397 (0.1035)	0.710	0.483
Cons	826.89 (53.350)	15.50	0.000	1.30700 (0.0420)	30.93	0.000

*MD = mean difference, R_{S1} = (ENR-grazing), R_{S2} = (ECNR-grazing), R_{S3} = (ECP-grazing), R_{F4} = (ENR-ECNR), R_{F5} = (ECNR-ECP), R_{H6} = Grazing-([ENR + ECNR + ECP]/3); R_{H7} = ENR-([ECNR + ECP]/2), and 'i' stands for woody plant species diversity and diversity. ENR, ECNR, and ECP stand for Exclosure for Natural Regeneration, exclosures of soil and water conservation structures only, and exclosures with soil and water conservation enriched with plantation.

TABLE 2 Comparison of woody plant species canopy and herbaceous cover (%) among exclosure management types in Tanqua-Abergele district (Obs = 72).

	Canopy cover			Herbaceous cover		
*MD	$\beta \pm$ SE	t	p	$\beta \pm$ SE	t	p
R_{S8i}	22.83 (5.05)	4.52	0.000	14.53 (5.86)	2.48	0.016
R_{S9i}	15.11 (5.05)	2.99	0.004	12.97 (5.86)	2.21	0.030
R_{S10i}	14.72 (5.05)	2.91	0.005	21.84 (5.86)	3.72	0.000
R_{F11i}	7.722 (5.05)	1.53	0.131	1.56 (5.86)	0.27	0.791
R_{F12i}	0.39 (5.05)	0.08	0.939	−8.87 (5.86)	−1.51	0.135
R_{H13i}	−17.56 (4.13)	−4.25	0.000	−16.45 (4.79)	−3.43	0.001
R_{H14i}	7.92 (4.38)	1.81	0.075	−2.88 (5.08)	−0.57	0.573
Constant	31.11 (1.79)	17.41	0.000	27.64 (2.07)	13.33	0.000

*MD = mean difference, R_{S8} = (ENR-grazing), R_{S9} = (ECNR-grazing), R_{S10} = (ECP-grazing), R_{F11} = (ENR-ECNR), R_{F12} = (ECNR-ECP), R_{H13} = Grazing-((ENR + ECNR + ECP)/3); R_{H14} = ENR-((ECNR + ECP)/2) and '*i*' stands for canopy and herbaceous covers.

TABLE 3 Comparison of above-ground woody and herbaceous species biomass (Kg/ha) among exclosure management types in Tanqua-Abergele district (Obs = 72).

	Above-ground woody biomass			Herbaceous biomass		
*MD	β ± SE	t	p	β ± SE	t	p
R_{S15i}	11188.43 (3339.89)	3.35	0.001	163.95 (67.80)	2.42	0.018
R_{S16i}	7571.64 (3339.89)	2.27	0.027	176.41 (67.80)	2.60	0.011
R_{S17i}	11578.6 (3339.89)	3.47	0.001	327.99 (67.80)	4.84	0.000
R_{F18i}	3616.79 (3339.89)	1.08	0.283	−12.45 (67.80)	−0.18	0.855
R_{F19i}	−4006.96 (3339.89)	−1.20	0.234	−151.59 (67.80)	−2.24	0.029
R_{H20i}	−10112.9 (2727.01)	−3.71	0.000	−222.78 (55.36)	−4.02	0.000
R_{H21i}	1613.312 (2892.43)	0.56	0.579	−88.25 (58.72)	−1.50	0.137
Constant	13583.78 (1180.83)	11.50	0.000	349.71 (23.97)	14.59	0.000

*MD = mean difference, R_{S1} = (ENR-grazing), R_{S2} = (ECNR-grazing), R_{S3} = (ECP-grazing), R_{F4} = (ENR-ECNR), R_{F5} = (ECNR-ECP), R_{H6} = Grazing-((ENR + ECNR + ECP)/3); R_{H7} = ENR-((ECNR + ECP)/2) and '*i*' stands for above-ground and herbaceous biomasses.

models (RSM). Discussion points with key informants and focus groups were mainly utilized for triangulation. The Operating Characteristic Function (OCF) for the RSM graphs was obtained as:

$$OCF = \frac{P_{ix}(\theta)}{P_{ix-1}(\theta) + P_{ix}(\theta)}, \text{which is the same as}: \frac{exp[\theta - (\lambda_i + \sigma_x)]}{1 + exp[\theta - (\lambda_i + \sigma_x)]}, \quad (4)$$

where $P_{ix}(\theta)$ is the probability of scoring x on item i, $P_{ix-1}(\theta)$ is the probability of scoring $x-1$ on item i, θ is the location of the person on the construct, λ_i are the location of the items on the construct, and σ_x is the location on the construct where the probability of responding in adjacent categories, $x-1$ and 1, is equal across items.

3 | RESULTS

A significant regression equation was found ($p < 0.000$) on woody species density (Table 1). The average woody plant species density was 363, 1148, 993, and 803 plants per hectare for Grazing, ENR, ECNR, and ECP, respectively. However, no significant difference was found between ENR and AR as well as between ECNR and ECP. Similarly, a significant regression equation for Shannon biodiversity index was calculated ($p < 0.044$) on woody species diversity. Significantly higher woody species diversity was calculated in exclosures as compared to grazing. No significant difference was shown between ECNR versus ENR, ECNR versus ECP, and ENR versus AR. We found significant regression equation for canopy ($p < 0.000$) and herbaceous cover ($p < 0.004$). It was determined that canopy and herbaceous covers were 17.56% and 16.4% higher in exclosures than grazing. However, no significant difference was found between ENR and AR as well as between ECNR and ECP in both canopy and herbaceous covers (Table 2).

A regression was calculated to predict woody and herbaceous biomass based on exclosure management types (Table 3). A significant regression equation was found ($p < 0.002$) on woody AGB. Woody biomass was 10112.9 kg/ha more in exclosures than grazing. However, no significant difference was found between ENR and AR as well as between ECNR versus ECP and ENR versus ECNR.

Moreover, we found a significant regression equation ($p < 0.000$) for herbaceous biomass (Table 3). The herbaceous biomass in exclosures was 222.8 kg/ha more than in grazing land. ECP produced 151.6 kg/ha more biomass than ECNR and was significant. We did not get a significant difference between ENR versus AR and ENR versus ECNR.

Individual interviewees were inquired to provide comparative ranking values of 1 (low), 2 (medium), and 3 (high) among exclosure types based on their capacity of vegetation recovery. Accordingly, ENR was given values 1 (4.2%), 2 (39.9%), and 3 (55.9%). ECP was given values 1, 2, and 3 by 18.4, 80.4 and 1.2% of the respondents, respectively. Finally, respondents who ranked ECNR 1, 2, and 3 were 87.6%, 12.1%, and 0.3%, respectively. These rankings clearly showed that ENR has the highest percent of respondents for rank 3 (55.9%), ECP has highest values for rank 2 (80.4%) and ECNR for rank 1 (87.6%).

The item response theory (IRT) model was used to predict the probability of the individual households interviewed to rate ENR, ECNR, and ECP based on their effectiveness on vegetation recovery. Three graphs were generated: (1) The Category Characteristic Curve (CCC) (Figure 2a) indicates the probability that an individual will rate ENR, ECNR, and ECP with the lowest rank 1, (2) the CCC (Figure 2b) is the probability that an individual will rate each EMTs with 2, and (3) the Boundary Characteristic Curve (Figure 2c) shows the probability that a respondent rates ENR, ECNR and ECP with 3. These graphs clearly demonstrated that the probability of the study participants to rate ENR with a scale of 3, 2, and 1 is high (Figure 2c) and low (Figure 2a,b). That means, the majority of the respondents rated ENR as the most effective for vegetation recovery with a rank of 3. As predicted in Figure 2c, ECNR was given the rank 1 by the majority of the respondents while ECP with rank 2.

4 | DISCUSSION

4.1 | Overall effect of exclosure on vegetation density, diversity, cover and biomass

When the frequently grazed and degraded lands were protected from animal and human disturbances, suppressed plants and plant seeds began to exponentially increase in the number and size that improved woody species density. If appropriately managed, such natural vegetation can dominate natural habitats quickly. This was in line with

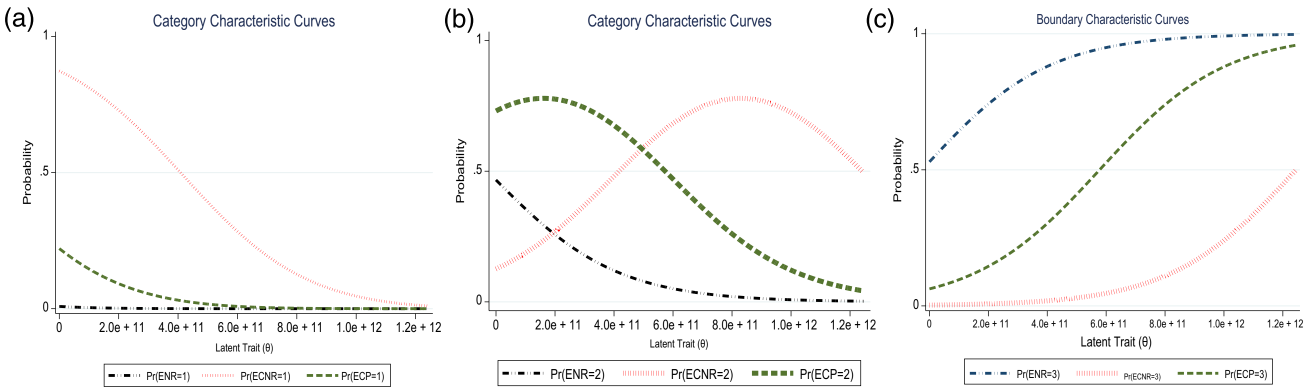

FIGURE 2 RSM models for household interviews on rating EMTs, 1 (a), 2 (b), and 3 (c); 1 being the lowest and 3 the highest ($n = 331$). [Colour figure can be viewed at wileyonlinelibrary.com]

Birhane et al. (2006), Desalew (2008), Fikadu and Argaw (2021) in Lemo, Asmare and Gure (2019) and Terefe et al. (2010) who reported higher woody plant density in exclosures than grazed areas in their studies in Tigray, Amhara and Southern regions of Ethiopia, respectively. Comparably, grazing exclusion restored cork tree regeneration (Köbel et al., 2021) in Central Portugal and plant density (Deng et al., 2014) in China. Tesfay (2016) synthesized various studies and confirmed that exclosures improved woody species density more than adjacent grazing lands.

Exclosures had 33.74% higher diversity index scores than grazed-lands. Evaluated individually, ENR, ECNR, and ECP significantly improved wood diversity by 40.5%, 33.43%, and 27.61%, respectively. Exclosures likely created favorable environments for some grazing-sensitive plants, especially during the seedling growth stage. Exclusion and decreasing intensity of grazing improved native plant abundance in the drylands of China (Deng et al., 2014). Soil erosion and degradation were relatively high on rangelands, and seizure played an important role in increasing wood diversity through the conservation of soil moisture and nutrients. Consistent with our results, Tang et al. (2016) found that exclosures improved biodiversity in erosion-prone areas of China.

The lowest canopy cover (17.9%) may be related mainly to frequent grazing in community areas, as opposed to exclusion areas where only illegal stray animals were grazed. By reducing the pressure on browsing sensitive plants in the exclosure area, the canopy cover of ENR, ECNR and ECP were significantly improved by 22.8%, 15.1% and 14.7%, respectively. This is consistent to the study by Firincioğlu et al. (2007) on the effects of long-term grazing exposures of rangeland plants in the central Anatolian region of Turkey and concluded that exclosure increased the percentage of vegetation cover. Houessou et al. (2012) pointed out that the more grazing intensity, the lesser canopy cover was. Haidarian et al. (2010) and Samadi-Khangah et al. (2021) also indicated that the canopy cover of plants inside the exclosure was significantly higher than outside.

The ENR, ECNR, and ECP significantly improved herbaceous cover by 14.5%, 13%, and 21.8% more than grazing, respectively. Other reports signified that heavily grazed arid and semi-arid savannas of Africa (Gemedo et al., 2006; Melak et al., 2019; Mphinyane & Rethman, 2006) showed lower herbaceous cover than adjacent exclosures. Samadi-Khangah et al. (2021) in their study in Iran reported a higher percentage cover inside the exclosures than outside. Studies (Desalew, 2008; Tsehay, 2007) proved that continuous grazing affected the quantity of plant litter at the soil surface and brought indirect pressures on the germination of available seeds. In line with Abesha (2014) and Tessema et al. (2011) in Ethiopia and Ombega et al. (2017) at Narok County in Kenya, this study suggested that reduced grazing intensity and frequency in exclosures increased herbaceous species cover than grazed-lands.

Improvement of herbaceous and woody biomasses in exclosures was in line with (Angassa & Oba, 2010; Ombega et al., 2017) who found that protection, gradually increased biomass of herbaceous plants. Similarly, Singh et al. (2011) and Mekuria and Aynekulu (2011) reported higher biomass production in exclosures in Ethiopia. Moreover, the low herbaceous dry matter yields in the communal grazing lands as compared to exclosures managed at different levels are supported by different studies (Gemedo et al., 2006; Shenkute et al., 2011). Appropriate grazing management through livestock exclusion has been found to improve above-ground biomass in areas that were severely degraded (Wasonga et al., 2011). Heavy grazing leads to extreme defoliation of herbaceous vegetation, decreasing standing biomass, often activated by a decline in net primary productivity, as the intensity of grazing increases (Bilotta et al., 2007; Mureithi et al., 2016). The higher biomass production of herbaceous plant species in the exclosure could be related to enhanced land management using soil and water conservation (Ruto, 2015) and protection from year-round grazing. Reduced grazing pressure enhanced herbaceous above-ground biomass in the rehabilitated areas (Ombega et al., 2017).

Exclosures were better rangeland management practices that improved biomass production than the constantly overgrazed and mismanaged communal lands (Hassen et al., 2010; Ibrahim, 2016). It was calculated that year-round protection by hired guards, establishment of 1280 meters/hectare of diverse SWC structures and plantations with nursery–grown seedlings for an average duration of 5.4 years were performed. These could have played great roles to qualify exclosures to outperform grazing areas in woody biomass production. A year-round grazing lowered biomass production (Verdoodt et al., 2010).

4.2 | Effect of natural regeneration on vegetation density, diversity, cover, and biomass

ENR showed higher woody plant species density (250 plants/ha), diversity (7.68%), canopy cover (7.9%), woody biomass (1613 $kgDM^{-1}ha$) but slightly less herbaceous cover (2.9%), and herbaceous biomass (88 $kgDM^{-1}ha$), than AR. Generally, it was noted that AR was more disturbed during establishment to accommodate space for SWC and plantation interventions which required more time to recover than ENR. The relatively low canopy cover on AR as compared to ENR would be, on one hand, attributed to human disturbance during the construction of new and maintenance of older SWC structures and illegal grazing by animals. A recent critical analysis of exclosure governance (Araya et al., 2023) in the study area indicated that illegal grazing and low public participation were behind the exclosures' sustainability problems. FGDs indicated that the key problem of SWC and plantation practices was the massive cutting of trees to give space for the construction of physical structures and plantations. Local people clarified that the conservation activities had been very destructive which could have hindered enhanced vegetation recovery in AR. The periodic disturbances could have increased gaps, curtailed the germination of seeds, and the survival of juvenile seedlings. A case-studies synthesis on rehabilitation of degraded lands in Sub-Saharan Africa by Blay et al. (2004) revealed that cutting of significant vegetation occurs in AR. Mebrat (2015) reported that natural regenerations with minimized cutting effects are superior techniques than the aided ones. van Ulft (2004) viewed that germination, juvenile growth, and mortality can be affected by larger gaps created through the cutting of woody species.

Non-significant differences in woody species density, diversity, cover, and biomass between ENR and AR showed that additional management did not meet vegetation improvement expectations. This may be related to the fact that no clear conservation goals were set when the closure was initiated. It was calculated that 54% of the exclosures were established just in compliance with the regional plans of fulfilling quota figures without diagnosing the degradation levels. An important note by Shono et al. (2007) stated that the decisions on which reforestation approach to use, on a particular site, depends on the severity of degradation, the self-recovery potential of the land, demography of the area, and availability of financial and human resources, among other factors. Even after proper diagnosis of degraded lands within the target areas, adoption of natural, assisted, or simultaneous regenerations to restore degraded lands requires a thorough understanding of the effectiveness of each in the particular landscapes. In Brazil, registered landowners can take 2–4 years to evaluate which restoration method (or combination of methods) to adopt, with large implications for their cost (Brancalion et al., 2016). By observing the initial stages of colonization on the land over this period, farmers can better determine whether natural regeneration (which is far less costly than tree planting) is likely to be a successful method for restoration on their farm (Holl & Aide, 2011). Ferraz et al. (2014) noted that natural regeneration can even succeed in steep slopes with marginal value for industrialized agriculture and thus have low opportunity costs for other uses.

Therefore, ENR is a potentially suitable strategy for immediate exclosure recruitment, large-scale restoration, and comparable results in dry lands. If interventions to facilitate quick vegetation recovery is unavoidable, Holl and Aide (2011) recommended removing barriers to seed dispersal and seedling establishment at the local level. ENR projects can be boosted through seeding, providing perches for dispersers, transplanting, and protection of sprouts from fire and grazers, removing weeds, and intensive monitoring. Comprehensively, the effectiveness of ENR can be supported with the identification and marking regenerative seedlings and enhance their growth by liberating them from competition. Additionally, suppressing weedy vegetation through lodging (Shono et al., 2007) and herbicides (Cohen et al., 1995; Shono et al., 2007) can manifest better outcomes. Protection from disturbances, for example, firebreaks (Friday et al., 1999; Shono et al., 2007) and guarding from grazing livestock (Uriarte & Chazdon, 2016) were highlighted as useful enhancements to natural regeneration. Furthermore, maintenance and enrichment planting to enhance diversity and native large-seeded trees that might not regenerate naturally are useful practices (Shono et al., 2007).

Prioritization of natural regeneration as a restoration approach will lower the overall costs of restoration, may permit larger areas of recruitment and can achieve the best possible outcomes for recovering ecosystem functions, services, and biodiversity at scale in ways that improve livelihoods and promote strong, local governance and stewardship (Chazdon, 2017; Chazdon & Guariguata 2016; Uriarte & Chazdon, 2016). These can ensure the recruitment of considerably degraded areas in many tropical countries that cannot be economically rehabilitated for agricultural uses or commercial plantations. Organizations, communities, and governments are opting for the most cost-effective approaches to restore forests at large spatial scales (Chazdon & Uriarte, 2016; Sabogal et al., 2015) to meet global and local restoration commitments (Pistorius & Freiberg, 2014). Natural regeneration presents a potential solution to fill the gap due to its low recruitment costs than those based on planting trees (Birch et al., 2010; Chazdon & Uriarte, 2016) and applicability at scale.

4.3 | Effect of ECP on vegetation density, diversity, cover, and biomass

Conserved moisture on soil bands and plantation pits could have assisted herbaceous plants in ECP to have significantly higher biomass than in ECNR. This is because annual and shallow-rooted herbaceous species utilize moisture from the soil surface layers (Dimitrakopoulos & Bemmerzouk, 2003). Plantation pits assisted comparable plant growth in moisture-stressed dryland areas of Halaba (Kelbore & Gebreyes, 2022). On the other hand, the non-significant differences in woody species density and diversity reaffirm that ECP was not superior to ECNR in the recruitment of new plants. It was calculated that an average plantation of 3120 seedlings and seeding and sowing of 1.28 kilometers of bands per hectare per year were performed for an average of 5.4 years. Several reasons could have played their role in hindering the survival of seedlings in artificially enriched exclosures. One key hindrance was related to drought as newly introduced seedlings and germinated seeds were unable to survive low moisture and high temperatures of the drylands because trees primarily depend on the moisture status of the deeper soil layers (Dimitrakopoulos & Bemmerzouk, 2003). Consistent with this study, Hall (2008) found that drought was responsible for 13% of seedling deaths. Drought limited the survival of wet origin species in Isthmus of Panama dry forest which was linked to the physiological tolerance hypothesis (Gaviria & Engelbrecht, 2015). Other problems could be related to invasive weeds and pests as revealed by field observations and discussions with locals that the soil and water conservation structures harbor some rodents and small ruminant herbivores which could have played a negative role on the side of ECP hindering it to outperform ECNR in density and diversity. Introduced non-native seedlings and young plants are prone to such enemies. In line with this, Hall (2008) reported that 48% of seedlings died from predation and uprooting by small mammals in the Central African Republic. Likewise, unexpected outcomes and high failure rates were reported to be ubiquitous in ECP projects (Uriarte & Chazdon, 2016). SDG (2013) highlighted that the survival of seedlings was not promising in many exclosures. This made the additional costs of SWC, plantation, and sowing of grass seeds in AR of less impact on vegetation. It took each ECNR 3.8 and ECP 3.7 years of SWC practices making it very expensive and time-consuming. Many studies were in agreement with ours (Birch et al., 2010; Birhane et al., 2017; Chazdon & Uriarte, 2016;

FAO and UNCCD, 2015; Holl & Aide, 2011; SDG, 2013). This can limit large-scale implementation of the ECP program (FAO, 2019). Therefore, the insignificant difference in density, diversity, cover, and biomass between ECNR and ECP, on the other hand, stipulated that extra management did not meet expectations. Costs of plantation can reach as high as $2000–10,000 per/hectare with a fewer than half seedling survival rates (SDG, 2013). Estimated costs can reach 837 billion USD to restore 350 hectares in 15 years (FAO and UNCCD, 2015).

Individual interviewees rated ECP to be the second option with an IRT graph score of 2. Consistent with this, Griscom and Ashton (2011) and Mebrat (2015) reported that tree planting can ameliorate poor soil conditions that limit natural regeneration. Holl and Aide (2011) and Hardwick and Elliott (2016) stated that active restoration can accelerate natural regeneration and stand development processes when the spontaneous establishment of trees is insufficient to create conditions for successful native plant regeneration and forest development. Therefore, stakeholders should be aware of the costs and availability of funds when ECP are decided to be used as mandatory options for restoration.

5 | CONCLUSION

Effects of exclosure management types on woody species density, diversity, biomass, and canopy cover as well as herbaceous cover and biomass were improved. The establishment of Natural Regenerating Exclosures (ENR) as a management type produced comparable or higher results in cover, density, diversity, and biomass to ECNR and ECP. This makes ENR a superior or equally feasible option to ECNR and ECP to restore degraded dryland grazing areas. Restoration approaches need to be selected based on community objectives, level of degradation, and availability of resources and time which requires prior scientifically established research recommendations. Precisely, we recommend exclosure establishment to begin with quick large-scale ENR and then switching the non-responsive lands into ECNR and ECP.

ACKNOWLEDGMENTS

We thank Danish International Development Agency (DANIDA) for funding this research project. We are grateful to the University of Nairobi, Mekelle University, and IGAD for providing us with resources and time to conduct the research. We extend our gratitude to all experts and farmers engaged during data collection and laboratory work.

CONFLICT OF INTEREST STATEMENT

On behalf of all authors, the corresponding author affirms that there is no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Haileselassie Ghebremariam Araya https://orcid.org/0000-0002-7562-864X

REFERENCES

Abesha, G. A. (2014). Herbaceous vegetation restoration potential and soil physical condition in a mountain grazing land of eastern Tigray, Ethiopia. *Journal of Agriculture and Environment for International Development*, *108*, 81–106. https://doi.org/10.12895/jaeid.20141.212.

Angassa, A., & Oba, G. (2010). Effects of grazing pressure, age of enclosures and seasonality on bush cover dynamics and vegetation composition in Southern Ethiopia. *Journal of Arid Environments*, *74*, 111–120. https://doi.org/10.1016/j.jaridenv.2009.07.015.

Araya, H. G., Wasonga, O. V., Mureithi, S., Birhane, E., & Mtimet, N. (2023). Low public participation and weak rules threaten exclosure sustainability in Tigray, Northern Ethiopia. *Socio-Ecological Practice Research*, *5*, 93–109. https://doi.org/10.1007/S42532-023-00140-2.

Asmare, M. T., & Gure, A. (2019). Effect of exclosure on woody species diversity and population structure in comparison with adjacent open grazing land: The case of Jabi Tehnan district north western Ethiopia. *Ecosystem Health and Sustainability*, *5*, 98–109. https://doi.org/10.1080/20964129.2019.1593794.

Bainbridge, D. A. (2017). Global guidelines for the restoration of degraded forests and landscapes in drylands: Building resilience and benefitting livelihoods. *Restoration Ecology*, *25*, 148–149. https://doi.org/10.1111/rec.12483.

Balana, B. B., Muys, B., Haregeweyn, N., Descheemaeker, K., Deckers, J., Poesen, J., Nyssen, J., & Mathijs, E. (2012). Cost-benefit analysis of soil and water conservation measure: The case of exclosures in northern Ethiopia. *Forest Policy and Economics*, *15*, 27–36. https://doi.org/10.1016/j.forpol.2011.09.008.

Bilotta, G. S., Brazier, R. E., & Haygarth, P. M. (2007). The impacts of grazing animals on the quality of soils, vegetation, and surface waters in intensively managed grasslands. *Advances in Agronomy*, *94*, 237–280. https://doi.org/10.1016/S0065-2113(06)94006-1.

Birch, J. C., Newton, A. C., Aquino, C. A., Cantarello, E., Echeverría, C., Kitzberger, T., Schiappacasse, I., & Garavito, N. T. (2010). Cost-effectiveness of dryland forest restoration evaluated by spatial analysis of ecosystem services. *Proceedings of the National Academy of Sciences of the United States of America*, *107*, 21925–21930. https://doi.org/10.1073/pnas.1003369107.

Birhane, E., Mengistu, T., Seyoum, Y., Hagazi, N., Putzel, L., Rannestad, M. M., & Kassa, H. (2017). Exclosures as forest and landscape restoration tools: Lessons from Tigray region, Ethiopia. *International Forestry Review*, *19*, 37–50. https://doi.org/10.1505/146554817822330498

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. *Journal of Dryland Agriculture*, *1*, 134–147.

Blay, D., Bonkoungou, E., Chamshama, S. A. O., & Chikamai, B. (2004). Rehabilitation of degraded lands in sub-Saharan Africa: Lessons learned from selected case studies, First. European Tropical Forest Research Network.

Brancalion, P. H. S., Schweizer, D., Gaudare, U., Mangueira, J. R., Lamonato, F., Farah, F. T., Nave, A. G., & Rodrigues, R. R. (2016). Balancing economic costs and ecological outcomes of passive and active restoration in agricultural landscapes: The case of Brazil. *Biotropica*, *48*, 856–867. https://doi.org/10.1111/btp.12383.

Chazdon, R. L. (2017). Landscape restoration, natural regeneration, and the forests of the future. *Annals of the Missouri Botanical Garden*, *102*, 251–257. https://doi.org/10.3417/2016035.

Chazdon, R. L., & Guariguata, M. R. (2016). Natural regeneration as a tool for large–scale forest restorationin the tropics: prospects and challenges. *Biotropica*, *48*, 716–730

Chazdon, R. L., & Uriarte, M. (2016). The role of natural regeneration in large-scale forest and landscape restoration: Challenge and opportunity. *Biotropica*, *48*, 709–715. https://doi.org/10.1111/btp.12409

Cohen, A. L., Singhakumara, B. M. P., & Ashton, P. M. S. (1995). Releasing rain forest succession: A case study in the Dicranopteris linearis Fernlands of Sri Lanka. *Restoration Ecology*, *3*, 261–270. https://doi.org/10.1111/j.1526-100X.1995.tb00093.x

Cornell, A., Weier, J., Stewart, N., Spurgeon, J., Etter, H., Thomas, R., Favretto, N., Chilombo, A., van Duivenbooden, N., van Beek, C., & de Ponti, T. (2016). Economics of land degradation initiative—report for the private sector. Sustainable land management—A Business Opportunity. GIZ. www.eld-initiative.org

Coulloudon, B., Eshelman, K., Gianola, J., Habich, N., Pellant, M., Hughes, L., Johnson, C., Podborny, P., Rasmussen, A., Robles, B., Shaver, P., Spehar, J., & Willoughby, J. (1996). Sampling vegetation attributes: Interagency Technical Reference, BLMTechnical Reference. National Applied Resource Sciences Center.

Deng, L., Sweeney, S., & Shangguan, Z. P. (2014). Grassland responses to grazing disturbance: Plant diversity changes with grazing intensity in a desert steppe. *Grass and Forage Science*, *69*, 524–533. https://doi.org/10.1111/gfs.12065.

Desalew, T. (2008). Assessment of feed resources and rangeland condition in Metema District of North Gondar zone, Ethiopia. *Ethiopian farmers Project Working Paper*, *25*(4), 142.

Descheemaeker, K., Nyssen, J., Rossi, J., Poesen, J., Haile, M., Raes, D., Muys, B., Moeyersons, J., & Deckers, S. (2006). Sediment deposition and pedogenesis in exclosures in the Tigray highlands, Ethiopia. *Geoderma*, *132*, 291–314. https://doi.org/10.1016/j.geoderma.2005.04.027.

Dimitrakopoulos, A. P., & Bemmerzouk, A. M. (2003). Predicting live herbaceous moisturecontent from a seasonal drought index. *International Journal of Biometeorology*, *47*, 73–79. https://doi.org/10.1007/s00484-002-0151-1.

ELD Initiative. (2015). Report for policy and decision makers: Reaping economic and environmental benefits from sustainable land management. 26. www.eld-initiative.org.

Ellen, W. (2011). Participatory forest management, practices and experiences. SFE Technical paper: FAO subregional Office for Eastern Africa (SFE), Ethiopia. 58.

FAO. (2019). *Restoring forest landscapes through assisted natural regeneration (ANR) a practical manual*. Food and Agriculture Organization of the United Nations.

FAO, & UNCCD. (2015). Sustainable financing for forest and landscape restoration.

Federal Democratic Republic of Ethiopia. (2012). Ethiopia's climate-resilient green economy—Green economy strategy 1–188.

Ferraz, S. F. B., Ferraz, K. M. P. M. B., Cassiano, C. C., Brancalion, P. H. S., da Luz, D. T. A., Azevedo, T. N., Tambosi, L. R., & Metzger, J. P. (2014). How good are tropical forest patches for ecosystem services provisioning? *Landscape Ecology*, *29*, 187–200. https://doi.org/10.1007/s10980-014-9988-z.

Fikadu, A., & Argaw, M. (2021). Impact of exclosures on woody species diversity in degraded lands: The case of Lemo in southwestern Ethiopia. *Heliyon*, *7*, e06898. https://doi.org/10.1016/j.heliyon.2021.e06898.

Friday, K. S., Drilling, M. E., & Garrity, D. (1999). Imperata grassland rehabilitation using Agroforestry and Assisted Natural Regeneration. International Centre for Research in Agroforestry, Southeast Asian Regional Research Programme.

Firincioğlu, H. K., Seefeldt, S. S., & Şahin, B. (2007). The effects of long-term grazing exclosures on range plants in the central Anatolian region of Turkey. *Environmental Management*, *39*, 326–337. https://doi.org/10.1007/s00267-005-0392-y.

Gebremichael, Y., & Waters-Bayer, A. (2007). *Trees are our backbone: Integrating environment andlocal development in Tigray Region of Ethiopia Issue, Russell The Journal Of The Bertrand Russell Archives*. Russel Press.

Gaviria, J., & Engelbrecht, B. M. J. (2015). Effects of drought, pest pressure and light availability on seedling establishment and growth: Their role for distribution of tree species across a tropical rainfall gradient. *PLoS One*, *10*, 1–20. https://doi.org/10.1371/journal.pone.0143955.

Gemedo, D., Maass, B. L., & Isselstein, J. (2006). Rangeland condition and trend in the semi-arid Borana lowlands, southern Oromia, Ethiopia. *African Journal of Range & Forage Science*, *23*, 49–58. https://doi.org/10.2989/10220110609485886.

Gilbey, B., Davies, J., Metternicht, G., & Magero, C. (2019). Taking land degradation neutrality from concept to practice: Early reflections on LDN target setting and planning. *Environmental Science & Policy*, *100*, 230–237. https://doi.org/10.1016/j.envsci.2019.04.007.

Gilman, A. C., Letcher, S. G., Fincher, R. M., Perez, A. I., Madell, T. W., Finkelstein, A. L., & Corrales-Araya, F. (2016). Recovery of floristic diversity and basal area in natural forest regeneration and planted plots in a costa Rican wet forest. *Biotropica*, *48*, 798–808. https://doi.org/10.1111/btp.12361.

Griscom, H. P., & Ashton, M. S. (2011). Restoration of dry tropical forests in Central America: A review of pattern and process. *Forest Ecology and Management*, *261*, 1564–1579. https://doi.org/10.1016/j.foreco.2010.08.027.

Haidarian, A. M., Naghipour, A. A., & Nasri, M. (2010). The effects of exclosure on vegetation and soil chemical properties in Sisab rangelands, Bojnord, Iran. *Journal of Renewable Natural Resources*, *1*, 14–27.

Hall, J. S. (2008). Seed and seedling survival of African mahogany (Entandrophragma spp.) in the Central African Republic: Implications for forest management. *Forest Ecology and Management*, *255*, 292–299. https://doi.org/10.1016/j.foreco.2007.09.050.

Hardwick, K., & Elliott, S. (2016). Second growth: The promise of tropical rain Forest regeneration in the age of deforestation. *Restoration Ecology*, *24*, 137. https://doi.org/10.1111/rec.12320.

Hassen, A., Ebro, A., Kurtu, M., & Treydte, A. C. (2010). *Livestock feed resources utilization and management as influenced by altitude in the central highlands of Ethiopia* (p. 22). Livestock Research for Rural Development.

Holl, K. D., & Aide, T. M. (2011). When and where to actively restore ecosystems? *Forest Ecology and Management*, *261*, 1558–1563. https://doi.org/10.1016/j.foreco.2010.07.004.

Houessou, L., Teka, A., Oumorou, M., & Sinsin, B. (2012). Hemicryptophytes plant species as indicator of grassland state in semi-arid region: Case study of W biosphere reserve and its surroundings area in Benin (West Africa). *International Journal of Biological and Chemical Sciences*, *6*, 1271–1280. https://doi.org/10.4314/ijbcs.v6i3.30.

Ibrahim, M. A. (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*, 157. https://doi.org/10.4172/2332-2543.1000157

Jabbar M. A., Pender J., & Ehui S. K. (eds). (2000). Policies for sustainable land management in the highlands of Ethiopia: Summary of papers and proceedings of a seminar held at ILRI, Addis Ababa, Ethiopia, 22–23 May 2000. Socio-economics and Policy Research Working Paper 30. ILRI (International Livestock Research Institute), Nairobi, Kenya. 68.

Jiapaer, G., Chen, X., & Bao, A. (2011). A comparison of methods for estimating fractional vegetation cover in arid regions. *Agricultural and Forest Meteorology*, *151*, 1698–1710. https://doi.org/10.1016/j.agrformet.2011.07.004.

Kebrom, T. (2001). Natural regeneration of degraded hillslopes in southern Wello, Ethiopia: A study based on permanent plots. *Applied Geography*, *21*, 275–300. https://doi.org/10.1016/S0143-6228(01)00006-6

Kelbore, Z. A., & Gebreyes, E. A. (2022). Evaluation of different soil moisture conservation structures in selected moisture stressed dry lands areas of Halaba, Southern Ethiopia. *Journal of Earth Science & Climatic Change*, *13*. https://doi.org/10.4172/2157-7617.1000612.

Köbel, M., Listopad, C. M. C. S., Príncipe, A., Nunes, A., & Branquinho, C. (2021). Temporary grazing exclusion as a passive restoration strategy in a dryland woodland: Effects over time on tree regeneration and on the shrub community. *Forest Ecology and Management*, *483*, 118732. https://doi.org/10.1016/j.foreco.2020.118732.

Latawiec, A. E., Crouzeilles, R., Brancalion, P. H. S., Rodrigues, R. R., Sansevero, J. B., dos Santos, J. S., Mills, M., Nave, A. G., & Strassburg, B. B. (2016). Natural regeneration and biodiversity: A global meta-analysis and implications for spatial planning. *Biotropica*, *48*, 844–855. https://doi.org/10.1111/btp.12386.

Lemenih, M., & Kassa, H. (2014). Re-greening Ethiopia: History, challenges and lessons. *Forests*, *5*, 1896–1909. https://doi.org/10.3390/f5081896.

Mebrat, W. (2015). Natural regeneration practice in degraded high lands of Ethiopia through area enclosure. *International Journal of Environmental Protection and Policy*, *3*, 120. https://doi.org/10.11648/j.ijepp.20150305.11.

Mekuria, W., & Aynekulu, E. (2011). Exclosure land Management for Restoration of the soils in degraded communal grazing lands in northern Ethiopia. *Land Degradation & Development*, *24*, 528–538. https://doi.org/10.1002/ldr.1146

Mekuria, W., Barron, J., Dessalegn, M., & Adimassu, Z. (2017). Exclosures for ecosystem restoration and economic benefits in Ethiopia: A catalogue of management options.

Melak, Y., Angassa, A., & Abebe, A. (2019). Effects of grazing intensity to water source on grassland condition, yield and nutritional content of selected grass species in Northwest Ethiopia. *Ecological Processes*, *8*. https://doi.org/10.1186/s13717-019-0162-z.

Mphinyane, W. N., & Rethman, N. F. G. (2006). Livestock utilisation of grass species at different distances from water on both traditional cattle post and ranch management systems in Botswana. *African Journal of Range & Forage Science*, *23*, 147–151. https://doi.org/10.2989/10220110609485897.

Munro, R. N., Woldegerima, T., Hailu, B., Zenebe, A., Gebremedhin, Z., Hailemichael, A., & Nyssen, J. (2019). A history of soil and water conservation in Tigray. In *Geo-trekking in Ethiopia's Tropical Mountains*. Springer Nature. https://doi.org/10.1007/978-3-030-04955-3_32.

Mureithi, S. M., Verdoodt, A., Njoka, J. T., Gachene, C. K. K., Warinwa, F., & Van Ranst, E. (2016). Impact of community conservation management on herbaceous layer and soil nutrients in a Kenyan semi-arid Savannah. *Land Degradation & Development*, *27*, 1820–1830. https://doi.org/10.1002/ldr.2315.

Murthy, I. K., Murali, K. S., Hegde,G. T., Bhat, P. R., & Ravindranath, N. H. (2002). A comparative analysis ofregeneration in natural forests and joint forest management plantations in Uttara Kannada district, Western Ghats. *Current Science*, *83*, 1358–1364.

Nedessa, B., Ali, J., & Nyborg, I. (2005). *Exploring ecological and socio-economic issues for the improvement of area enclosure management* (Vol. 63). Digital Currency Group Representative.

Nyssen, J., Descheemaeker, K., Zenebe, A., Poesen, J., Deckers, J., & Haile, M. (2009). Transhumance in the Tigray highlands (Ethiopia). *Mountain Research and Development*, *29*, 255–264. https://doi.org/10.1659/mrd.00033.

Ombega, N. J., Mureithi, S. M., Koech, O. K., Karuma, A. N., & Gachene, C. K. K. (2017). Effect of rangeland rehabilitation on the herbaceous species composition and diversity in Suswa catchment, Narok County, Kenya. *Ecological Processes*, *6*, 1–9. https://doi.org/10.1186/s13717-017-0109-1.

Pistorius, T., & Freiberg, H. (2014). From target to implementation: Perspectives for the international governance of forest landscape restoration. *Forests*, *5*, 482–497. https://doi.org/10.3390/f5030482.

Raunkiaer, C. (1934). The Life Forms of Plants and Statistical Plant Geography. Oxford University Press.

Ruto, A. C. (2015). Optimizing moisture and nutrient variability under different cropping patterns in terraced farms for improved crop performance in Narok county, Kenya.

Sabogal, C., Besacier, C., & McGuire, D. (2015). Forest and landscape restoration: Concepts, approaches and challenges for implementation. *Unasylva*, *66*, 3–10.

Samadi-Khangah, S., Ghorbani, A., Choukali, M., Moameri, M., Badrzadeh, M., & Motamedi, J. (2021). Effect of grazing Exclosure on vegetation characteristics and soil properties in the Mahabad Sabzepoush rangelands. *Iran*, *9*, 139–152.

SDG. (2013). Reforesting Brazil's Biomes & Facilitating Biodiverse Genomic Flow between Atlantic rainforest fragments—United Nations partnerships for SDGs platform. [WWW Document]. URL https://sustainabledevelopment.un.org/partnership/?p=300 (accessed May 24, 2021)

Shannon, C. E. (1948). A mathematical theory of communication. *Bell System Technical Journal*, *27*, 379–423. https://doi.org/10.1002/j.1538-7305.1948.tb01338.x.

Shenkute, B., Hassen, A., Ebro, A., Asafa, T., & Amen, N. (2011). Identification of potential untapped herbaceous flora in the mid rift valley of Ethiopia and their nutritive value. *African Journal of Agricultural Research*, *6*, 4153–4158. https://doi.org/10.5897/AJAR11.085.

Shono, K., Cadaweng, E. A., & Durst, P. B. (2007). Application of assisted natural regeneration to restore degraded tropical forestlands. *Restoration Ecology*, *15*, 620–626. https://doi.org/10.1111/j.1526-100X.2007.00274.x.

Singh, G., Choadhary, G. R., Ram, B., & Limba, N. K. (2011). Effects of rainwater harvesting on herbage diversity and productivity in degraded Aravalli hills in western India. *Journal of Forest Research*, *22*, 329–340. https://doi.org/10.1007/s11676-011-0177-5.

StataCorp. (2017). Stata statistical software. Release 15. College Station, TX. StataCorp LLC.

Stavi, I., & Lal, R. (2015). Achieving zero net land degradation: Challenges and opportunities. *Journal of Arid Environments*, *112*, 44–51. https://doi.org/10.1016/j.jaridenv.2014.01.016.

Stocking, M. A. (2001). Land degradation. *International Encyclopedia of Social & Behavioral Sciences*, 8242–8247. https://doi.org/10.1016/B0-08-043076-7/04184-X.

Sutton, P. C., Anderson, S. J., Costanza, R., & Kubiszewski, I. (2016). The ecological economics of land degradation: Impacts on ecosystem service values. *Ecological Economics*, *129*, 182–192. https://doi.org/10.1016/j.ecolecon.2016.06.016.

Taddese, G. (2001). Land degradation: A challenge to Ethiopia. *Environmental Management*, *27*, 815–824. https://doi.org/10.1007/s002670010190.

Tang, J., Davy, A. J., Jiang, D., Musa, A., Wu, D., Wang, Y., & Miao, C. (2016). Effects of excluding grazing on the vegetation and soils of degraded sparse-elm grassland in the Horqin Sandy land, China. *Agriculture, Ecosystems & Environment*, *235*, 340–348. https://doi.org/10.1016/j.agee.2016.11.005.

Terefe, A., Ebro, A., & Zewedu, T. (2010). Rangeland dynamics in south Omo zone of Southern Ethiopia: Assessment of rangeland condition in relation to altitude and grazing types. *Livestock Research for Rural Development*, *22*(10).

Tesfay, A. (2016). The contribution of grazing enclosures for sustainable management and enhancing restoration of degraded range lands in Ethiopia: Lessons and forward. *Journal of Environment and Earth Science*, *6*(8), 112–126.

Tessema, Z. K., de Boer, W. F., Baars, R. M. T., & Prins, H. H. T. (2011). Changes in soil nutrients, vegetation structure and herbaceous biomass in response to grazing in a semi-arid savanna of Ethiopia. *Journal of Arid Environments*, *75*, 662–670. https://doi.org/10.1016/j.jaridenv.2011.02.004.

t'Mannetje, L., & Jones, R. M. (2000). *Field and laboratory methods for grassland and animal production research* (1st ed.). CABI Publishing.

Tsehay, L. (2007). *Woody and herbaceous species composition and the condition of the rangelands in Shinile zone of Somali regional state, Ethiopia*. Haramaya University.

Ubuy, M. H., Eid, T., Bollandsås, O. M., & Birhane, E. (2018). Aboveground biomass models for trees and shrubs of exclosures in the drylands of Tigray, northern Ethiopia. *Journal of Arid Environments*, *156*, 9–18. https://doi.org/10.1016/j.jaridenv.2018.05.007.

Uriarte, M., & Chazdon, R. L. (2016). Incorporating natural regeneration in forest landscape restoration in tropical regions: Synthesis and key research gaps. *Biotropica*, *48*, 915–924. https://doi.org/10.1111/btp.12411.

van der Esch, S., S.V.D, Brink, B. T., Stehfest, E., Bakkenes, M., Sewell, A., Bouwman, A., Meijer, J., Westhoek, H., & Maurits van den Berg, M. V. D. (2017). Exploring the impact of changes in land use and land conditionon food, water, climate change mitigation and biodiversity: Scenarios for the UNCCD Global Land Outlook. The Hague.

van Ulft, L. H. (2004). Modelling seeddispersal and regeneration of tropical trees in Guyana. Tropenbos–Guyana. Tropenbos–Guyana, T. (Ed.), Tropenbos–Guyana Series. Tropenbos–Guyana Programme.

Verdoodt, A., Mureithi, S. M., & Van Ranst, E. (2010). Impacts of management and enclosure age on recovery of the herbaceous rangeland vegetation in semi-arid Kenya. *Journal of Arid Environments*, *74*, 1066–1073. https://doi.org/10.1016/j.jaridenv.2010.03.007.

Wasonga, O. V., Nyariki, D. M., & Ngugi, R. K. (2009). *Linkages between land-use, land degradation and poverty in semi-arid rangelands of Kenya: The case of Baringo District*. University of Nairobi.

Wasonga, V. O., Nyariki, D. M., & Ngugi, R. K. (2011). Assessing socio-ecological change dynamics using local knowledge in the semi-arid lowlands of Baringo District, Kenya. *Environmental Research Journal*, *5*, 11–17. https://doi.org/10.3923/erj.2011.11.17.

Wisborg, P., Shylendra, H. S., Gebrehiwot, K., Shanker, R., Tilahun, Y., Nagothu, U. S., Tewoldeberhan, S., & Bose, P. (2000). Rehabilitation of CPRS through Re-crafting of village institutions: A comparative study from Ethiopia and India. 8th Biennial Conference of the International Association for the Study of Common Property. 1–30.

Yayneshet, T. (2010). Feed Resources Availability in tigray region, northern Ethiopia, for production of export quality meat and livestock. Ethiopia Sanitary & Phytosanitary Standards and Livestock & Meat Marketing Program (SPS–LMM) Report. 77 pp.

Zingore, S., Mutegi, J., Agesa, B., & Tamene, L. (2010). Soil degradation in sub-Saharan Africa and crop production options for soil rehabilitation. *Better Crop With Plant Food*, *99*, 24–26.

How to cite this article: Araya, H. G., Wasonga, O. V., Mureithi, S., & Birhane, E. (2023). Natural regeneration offers an effective way for large-scale restoration of degraded lands in Tigray, Ethiopia. *Land Degradation & Development*, *34*(14), 4346–4357. https://doi.org/10.1002/ldr.4781