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Natural regeneration status of exclosures and open grazing areas in Northern Ethiopia

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Abstract

Land degradation is widespread and a serious threat affecting the livelihoods of many. It was found that the prospect of restoring degraded lands is technically promising using area exclosure. Data on vegetation were gathered from 90 quadrants from exclosures of different ages and 30 from adjacent free grazing lands. The seedling and sapling inventory were done by two subplots of 2 x 5 m established at the beginning and the end of the baseline on opposite sides of the main plot. A total of 27 sapling species belonging to 16 families was recorded. Sapling density ranges from 1000 to 21,000 saplings per ha (3197 ± 720). Fabaceae is the dominant family in the sapling. Similarly, a total of 17 seedling species belonging to 11 families was recorded. The overall seedling density ranges from 1000 to 12,000 seedlings per ha (2897 ± 980). Like sapling, fabaceae is the dominant family in the seedling. Analysis of seedling and sapling density indicated that both exclosures and free grazing areas were found to be dominated by few species. Local communities' participation, incorporation of indigenous ecological knowledge, is crucial for long-term success of rehabilitation activities.

Keywords: Seedling; Sapling; Exclosure; Regeneration; Northern Ethiopia

1. Introduction

Regeneration is a key ecological process and a central component of forest ecosystem dynamics and restoration of degraded forest lands. Sustainable forest utilization is only possible if adequate information on the regeneration dynamics and factors influencing important canopy tree species are available. If native long-lived trees are unable to survive and regenerate in a given forest, then there is little hope for maintaining any semblance of normal forest functioning in the long term [1].

Therefore, the effectiveness to maintain and expand forests will depend mainly on the success of natural regeneration of the component woody species. Densities of seedlings and saplings are considered an indicator of the regeneration potential of a forest. A species is considered in a good regeneration status if the number of seedlings is greater than saplings which in turn greater than tree (seedlings > saplings > tree); fair regeneration is a condition of a species where number of seedlings is greater than the number of saplings and the number of saplings is also less than the number of trees (seedlings > saplings < tree); poor regeneration is a status of regeneration where density of sapling is greater than seedlings. A species is considered not regenerating if it survives only in the adult stage and a species newly arrives if it presents only in seedling stage [2].

Species composition, structure and regeneration process could be affected by the frequency and magnitude of the disturbance. A good understanding of factors promoting or hampering the seedling establishment of tree species could help in the future restoration of degraded landscapes through the appropriate management system. Factors that

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potentially influence regeneration at the early stage are those that determine the probability of seedling establishment and those that affect seedling survival and growth. Seed availability can be influenced by local seed rain (recently dispersed seeds), soil seed bank (dormant seeds in the soil) and seedling bank (established, suppressed seedlings in the understory) [3]. Insufficient input of seed rain both in quality and quantity in forests may be attributed to fragmentation which brings about change in tree phenology as a result of increased mortality of reproductive individuals and/or genetic drift that might lead to a reduction of flowering and fruiting, fewer pollinators and dispersers, and increased pre-dispersal seed predation [4]. Reduced seed rain, lack of persistent soil seed bank and intense seed predation can decrease seed availability; this, in turn, creates a bottleneck for seedling establishment.

In some instances, the available seeds may not be able to establish seedlings due to the unfavorable microsite. Drastic variability and fluctuation in the microenvironment may lead to either seed mortality or seed dormancy resulting in reduced germination and successful establishment [3]. Another factor hampering early stage regeneration is related to seedling survival and growth. Once seeds have germinated and seedlings are established the next challenge is to survive, grow and join sapling and adult stage. Seedling mortality may increase due to unfulfilled optional requirements like light and moisture. In fragmented forests, a consequence of drastic variability and fluctuation in the physical microenvironment is crucial. Physical damage and destruction due to trampling and grazing, competition by weeds and herbs raise seedling mortality [5].

There are other factors determining regeneration dynamics of native woody species. From the long lists of these factors, grazing is a common practice in the study area. Grazing is believed to have both positive and negative roles in the regeneration of species. It has been suggested that a light level of grazing can increase tree regeneration by removing competitive vegetation, remove fire hazard and fertilize by droppings. Large herbivores can also create patches of bare ground through grazing and trampling. These disturbances may create “safe sites” for seeds to germinate [5]. On the other hand, continuous and intensive grazing may cause irreversible damage. The unrestricted animal movement may also destroy seeds and press them deep in the soil from where they are not able to emerge. Trampling and grazing of seedlings may lead to low seedling survival [6]. Though grazing has both negative and positive effects, the balance of evidence indicated that free and intensive livestock grazing has deleterious effects on regeneration of species through trampling and soil compaction.

Regeneration studies contribute to planning, conservation and decision making in forest resources management programs [2]. Several studies carried out on regeneration of different forests and forest patches elsewhere in Ethiopia [7]; [8]; [9], concluded that most forests are dominated by shrubby and lower size secondary type and regeneration rate of most indigenous species are hampered by anthropogenic activities. Therefore, conservation and sustainable utilization of the few remnant natural forests in Ethiopian highlands, which are potential sources of propagules, is an urgent task [7]. Information on the regeneration ecology of the different forest types in Ethiopia is scanty [3]. This study, therefore, focused on the natural regeneration of species in exclosures of Tigray, Ethiopia.

2. Material and methods

2.1. Study area

Tigray Region has five administrative zones, which are further sub-divided into 35 *Woredas* (districts). The study was conducted in three *Woredas/*Districts of Tigray, Ethiopia (12° - 15° N latitude and 36° 30' - 40° 30' E longitude) (Figure 1). We have used a total of 120 samples and 90 from exclosures of different ages, i.e., 10, 15 and 20 years, and ranging in size from 8 – 125 ha. Corresponding adjacent free grazing areas (2 – 45 ha in size) were used as a control and for comparisons. The exclosures were selected based on altitude (range between 1400 and 2900), the age of exclosures (vary between 1 and 25 years), size of exclosures (differ from 8 to 125 hectares), proportion of exclosure out of the total area, and distance from residence (vary in the range 0.5 to 9 kilometers). Fair accessibility is also under consideration. However, it is rare to find all the exclosure forms in a relatively homogenous environment, mainly, agro-ecological zone.

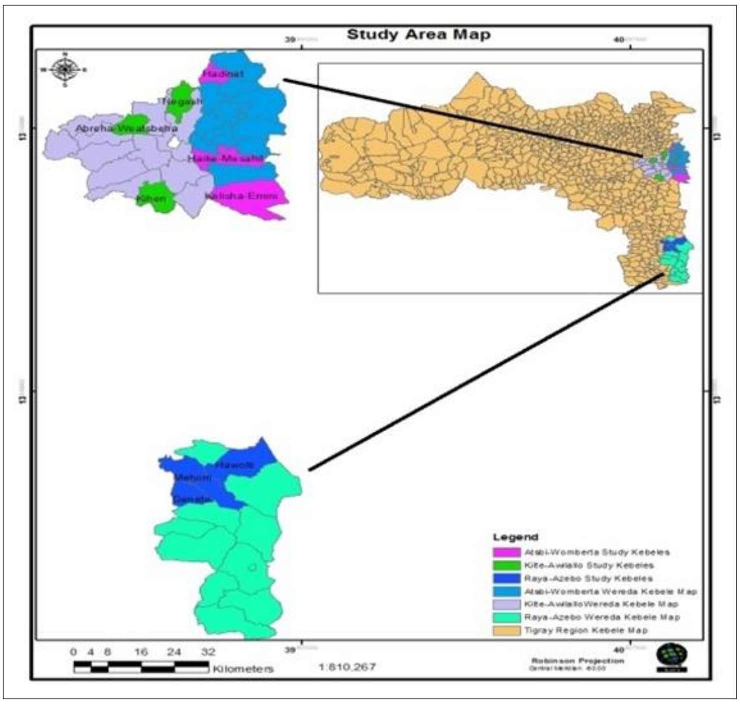


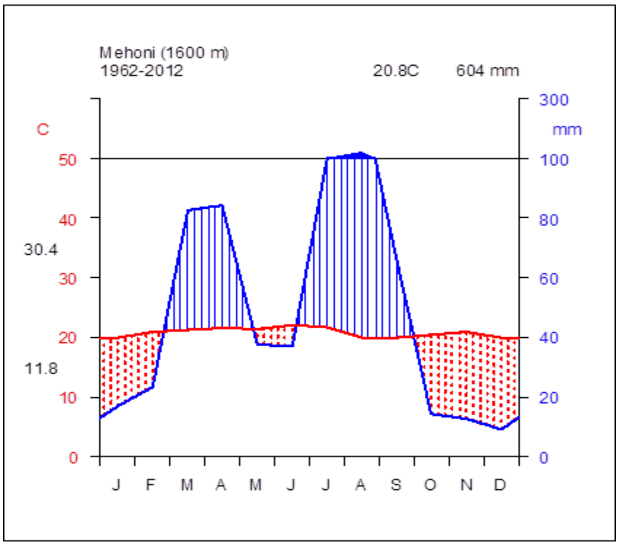
Figure 1 Map of Selected *Kebeles* of the Study areas

Soils of the AtsbiWemberta and KilteAwelaelo sites were classified into four major groups: Luvisols (Alfisols), Regosols (Entisols), Cambisols (Inceptisols) and Calcisols (Aridisols) [10]. And the Fluvisols are mainly confined to the alluvial deposits along the river valley [11]. A large part of areas vegetation is formed on Enticho sandstone and Crystalline Basement [12] While in Raya Azebo the dominant soil types are Leptosols, Cambisols, Vertisols, Regosols, and Arenosols [13]. Large parts of the undulating terrains in northern Ethiopia are characterized by shallow soils and frequent rock outcrops, while relatively thick soils are found along valley bottoms.

The topography of the areas comprises several forms from high slope to flat, ragged and deep gorges and gullies. Most of the areas were characterized by cleared forest and considered as the most degraded and eroded area in the previous time. The topography of Tigray contains the three main traditional divisions of arable Ethiopia: the *Kolla*– lowlands (c1400-1800 meters above sea level) with relatively low rainfall and high temperatures; the *Woinadega*– middle highlands (c1800-2400 m.a.s.l.) with medium rainfall and medium temperatures; *Dega*– highlands (c2400-3400 m a.s.l.) with somewhat higher rainfall and cooler temperatures.

Analysis of the meteorological data showed that the mean annual temperature for Raya Azebo was 20.8°C and the mean minimum and maximum were 11.8°C and 33.5°C respectively. The hottest months are April and June, while coldness is from September to December. The mean annual rainfall is 604 mm, which varied greatly from year to year. Generally, the study area has bimodal rainfall pattern, with low rainfall from February to May and the main rainy season (June – September). Kilite Awulaelo *Woreda* average daily air temperature of the area ranges between 8°C and 30.1°C with a mean of 19.7°C. The mean annual rainfall of the area is about 610 mm. Kilite Awulaelo *Woreda* has unimodal rainfall pattern (Figure 2A &B).

The most common woody vegetation species in exclosures and in adjacent grazing lands included *Acacia etbaica*, *Acacia seyal*, *Becium grandiflorum, Euclea racemosa* subsp.*Schimperi* and *Maytenus senegalensis*. Under storey vegetation of exclosures and free grazing lands were dominated by grass species such as *Hyparrhenia hirta* and *Digitaria ternata*.



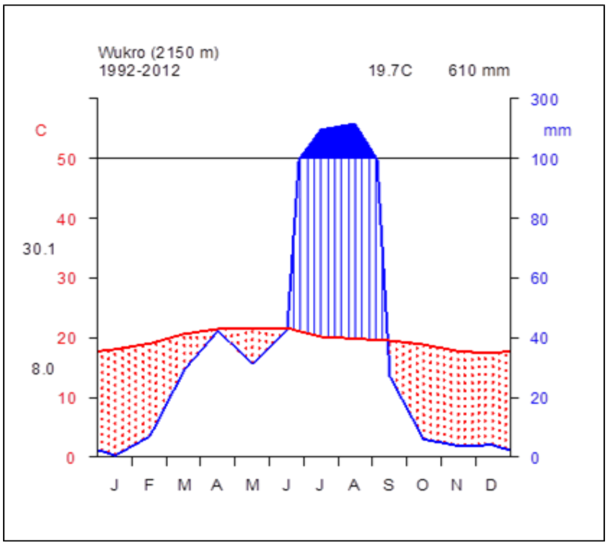


Figure 2 A and B Climatic diagram, A denotes Mehoni station, B denotes Wukro station

2.2. Data collection and analysis

Data on vegetation were gathered from 120 quadrants (90 from restorations or exclosures of different ages and 30 from adjacent free grazing lands), of 20 m x 20 m (400 m^2) size [14]; [15]; [16]. The seedling and sapling inventory were done by two subplots of 2 x 5 m established at the beginning and the end of the baseline on opposite sides of the main plot. According to Harper [17], studies on densities of age classes (seedlings and saplings plants) help to determine regeneration status of forests/vegetation. For the purpose of the study, seedlings, saplings, and mature trees/shrubs were categorized as seedling (height < 0.5 m), sapling (height between 0.5 m and 2 m) and tree/shrub (height > 2 m) following Emiru *et al.,* [18] and Feyera and Demel, [19].

Similarity index of regenerated plant species in the different stands was calculated using Jaccard's Coefficient of Similarity (JCS) [20]. Similarity of the regenerated flora and the aboveground flora was compared using JCS between average paired sample plots in which both regenerated and aboveground species data were available. Regeneration status of shrubs and trees for each of the exclosures was analyzed and compared by using the densities of different age classes (seedlings and saplings) whereas the regeneration status of the different age classes of restorations was analyzed and compared using density ratios between age classes (ratios between seedlings and saplings). Recruitment potential of the restorations was compared based on the number of seedlings to saplings using the non-parametric test. The computation was made using SPSS version 20 statistical software. Seedlings and saplings count in the two subplots were summed and considering as a value for a plot with an area of 20 m^2 finally converted to per hectare basis.

3. Results and discussion

3.1. Natural regeneration status on exclosures

A total of 27 sapling species belonging to 16 families was recorded. The overall sapling density ranges from 1000 to 21,000 saplings per ha (mean ± SE: 3197 ± 720). Like in the standing vegetation, Fabaceae (represented by eight species) is the dominant family in the sapling. Anacardiaceae, Celastraceae, Ranunculaceae, and Sapindaceae are each represented by two species and the remaining 11 families by one species (Table 2). The three most abundant species represented in the sapling are *Cadia purpurea* (17.7 % of the total individuals), *Maytenus senegalensis* (9.2 %), and *Opuntia ficus-indica* (7.8 %). The sapling is dominated by shrub species 14 species (50 %), followed by tree 6 species (21 %), herb species 5 species (18 %) andClimbers 3 species (11%). The similarity between the sapling and standing vegetation species composition is low (Sørensen coefficient of similarity = 22.5%). Only 14 % of the species in the standing vegetation is represented in the sapling and 8 new species are found in the sapling.

In case of free grazing, the number of species recorded was three and *Acacia asak*was the most dominant saplings and four species was recorded as a seedling and *Dodonea angustifolia* was the dominant seedling.

Ratio/proportion of seedlings to saplings showed the status of regeneration of a given forest ecosystem. A ratio of the seedling to sapling was also presented in Table 1.

Table 1 Abundance and frequency of seedling and saplings in exclosures and free grazing areas

	Seedling			Sapling			
	No Species	**Abundance ha^{-1}**	**Frequency ha^{-1}**	**No Species**	**Abundance ha^{-1}**	**Frequency ha^{-1}**	**Seedling to Sapling ratio (Abundance)**
Exclosure	17	2233.3	446.7	27	4866.7	973.3	0.46
Free grazing	4	250	43.3	3	216.7	50	1.15

The ratio of seedlings to saplings was generally low but high in free grazing (1.15) compared to exclosures (0.46)

Similarly, a total of 17 seedling species belonging to 11 families was recorded. The overall seedling density ranges from 1000 to 12,000 seedlings per ha (mean ± SE: 2897 ± 980). Like in the standing vegetation, Fabaceae (represented by five species) is the dominant family in the seedling. Celastraceae and Sapindaceae are each represented by two species and the remaining 8 families by one species (Table 3). The most abundant species represented in the seedling are *Maytenus arbutifolia, Senna singueana, Euclea schimperi, Dodonea angustifolia, Carissa edulis* and *Cadia purpurea*. The seedling bank is dominated by shrub species 9 species (53 %), followed by tree 5 species (29 %) and herb species 3 species (18 %). The similarity between the seedling and standing vegetation species composition is low (Sørensen coefficient of similarity = 16.4%). Only 9 % of the species in the standing vegetation is represented in the seedling and 4 new species are found in the seedling.

Table 2 Species identified in the sapling in the exclosures

Family	Species	Lifeform	Frequency in (%)	Density of Sapling ha^{-1}
Fabaceae	*Cadia purpurea*	Shrub	24.4	1188.9
Cactaceae	*Opuntia ficus-indica*	Shrub	15.1	733.3
Asteraceae	*Echinops giganteus*	Herb	5.5	266.7
Polygonaceae	*Rumex nervosus*	Herb	5.3	255.6
Lamiaceae	*Becium ovovatum*	Herb	5.0	244.4
Sapindaceae	*Cardiospermum corindum*	Herb	4.8	233.3
Apocynaceae	*Carissa edulis*	Shrub	4.3	211.1
Ebenaceae	*Euclea schimperi*	Shrub	4.1	200.0
Celastraceae	*Maytenus arbutifolia*	Tree	4.1	200.0
Celastraceae	*Maytenus senegalensis*	Shrub/Tree	4.1	200.0
Fabaceae	*Acacia melifera*	Tree	2.5	122.2
Rubiceae	*Coffea arabica*	Shrub	2.5	122.2
Sapindaceae	*Dodonea angustifolia*	Shrub	2.5	122.2
Fabaceae	*Dichrostachys cinerea*	Shrub/Tree	2.3	111.1
Tiliaceae	*Grewia sp.*	Shrub/Tree	2.3	111.1
Boraginaceae	*Cordia africana*	Tree	1.8	88.9
Rhamnaceae	*Rhamnus prinoides*	Shrub	1.8	88.9
Fabaceae	*Acacia etbaica*	Tree	1.6	77.8
Fabaceae	*Acacia tortilis*	Tree	1.4	66.7
Fabaceae	*Indigofera arrecta*	Shrub	1.4	66.7

Fabaceae	*Senna singueana*	Shrub	0.9	44.4
Fabaceae	*Acacia asak*	Shrub/Tree	0.5	22.2
Vitaceae	*Cissus quadrangularis*	Climber	0.5	22.2
Anacardiaceae	*Rhus natalensis*	Shrub	0.5	22.2
Anacardiaceae	*Rhus vulgaris*	Tree	0.5	22.2
Ranunculaceae	*Clematis hirsuta*	Climber	0.2	11.1
Ranunculaceae	*Clematis simensis*	Climber	0.2	11.1

Analysis of regeneration status of woody species in the entire study sites showed that the frequency distribution of age classes successively decreased from lower to higher age classes. A separate analysis of age classes for tree, shrubs and climber growth forms showed considerable variations in the trend of their frequency distribution. In all cases, thenormal frequency distribution of age classes was observed where the number of seedlings exceeded the number of saplings. Analysis of seedling and sapling density indicated that both exclosures and free grazing areas were found to be dominated by few species (Table 2 and 3).

Table 3 Species identified in the seedling in the exclosures

Family	Spps	Lifeform	Frequency in (%)	Density Seedling ha^{-1}
Sapindaceae	*Dodonea angustifolia*	Shrub	19.9	444.4
Fabaceae	*Cadia purpurea*	Shrub	10.4	233.3
Asteraceae	*Echinops giganteus*	Herb	10.4	233.3
Fabaceae	*Acacia etbaica*	Tree	8.5	188.9
Celastraceae	*Maytenus arbutifolia*	Tree	8.0	177.8
Fabaceae	*Indigofera arrecta*	Shrub	7.5	166.7
Apocynaceae	*Carissa edulis*	Shrub	6.5	144.4
Lamiaceae	*Becium ovovatum*	Herb	6.0	133.3
Sapindaceae	*Cardiospermum corindum*	Herb	5.0	111.1
Ebenaceae	*Euclea schimperi*	Shrub	3.0	66.7
Tiliaceae	*Grewia sp.*	Shrub/Tree	3.0	66.7
Anacardiaceae	*Rhus natalensis*	Tree	3.0	66.7
Fabaceae	*Senna singueana*	Shrub	3.0	66.7
Fabaceae	*Acacia asak*	Shrub/Tree	1.5	33.3
Capparaceae	*Boscia angustifolia*	Tree	1.5	33.3
Celastraceae	*Maytenus senegalensis*	Shrub/Tree	1.5	33.3
Oleaceae	*Olea europaea* subsp.*cuspidata*	Tree	1.5	33.3

For instance, Fabaceae the most species-rich (8 and 5 species) family in and the other families were represented by few species (less than 3 species) in the seedling and sapling population of each site. The ratio of seedlings to saplings was generally low but high in free grazing (1.15) compared to exclosures (0.46) (Table 1).

4. Conclusion

Restoration requires spatial planning to maximize effective long-term outcomes, engage diverse groups of stakeholders, and minimize overall costs. Natural regeneration of vegetation is the least expensive and most ecologically effective approach to large-scale forest restoration. Natural regeneration can also be assisted in ways that do not focus only on tree planting. Natural regeneration is promoted by high local resource availability and high propagule (i.e. seeds and sprouts) availability. Many future forests will grow up in predominantly degraded and deforested landscapes. Restoring functionality at the landscape scale does not require restoring the species composition of the original forest. But fostering natural regeneration in those areas where it is already occurring or likely to occur can conserve native species, sequester substantial amounts of carbon dioxide, enhance connectivity within the landscape, and allow limited expenses to be spent on tree planting in such or other strategic sites. These naturally regenerating plants will be critical habitats for species in the landscapes where vegetation patches coexist with other forms of land use and create sources for regeneration in planted forest areas.

Reasons for inadequate seedlings and saplings of some tree species in the study areas might be many, including grazing and browsing in free grazing areas, seed predation, lack of safe sites for seed recruitment, or the need of dormancy period for seeds of certain trees. Besides, moisture stress, pathogens, and possession of alternative adaptations for propagation other than seed germination could also be the cause for lack of sufficient seedlings.

The result indicate that exclosures could be useful to foster natural regeneration of native woody species They enhance the process of native forest succession over time by attracting seed dispersal agents and providing a nurse effect for the colonizing native species. As a result, exclosures can enhance plant diversity of indigenous species. However, the need to have seed sources in the vicinity to facilitate the regeneration of native woody species. It also appears that birds or mammals transport almost all woody species in the understory.

Therefore, it is very important to keep enough natural forest not only to maintain seed sources in the vicinity but also habitats for seed dispersing animals.

The rehabilitation of degraded areas in the exclosures were a good example of an effort to incorporate different natural, environmental, social, and health aspects and processes in order to understand and modify the drivers of degradation.

Communities' participation incorporation of indigenous ecological knowledge and practices, consideration of local peoples' short and long-term needs and value systems, clear division of tasks and benefits, strengthening of local organizations are crucial not only for benefit maximization, but also for the long-term success of degraded land rehabilitation. It is also necessary to investigate how the established native woody species can be manipulated to develop in to a secondary forest.

Compliance with ethical standards

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Disclosure of conflict of interest

All authors report no conflict of interest.

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