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The role of enclosures in the recovery of woody vegetation in degraded dryland hillsides of central and northern Ethiopia

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Abstract

The role of enclosures in the recovery of woody vegetation was investigated by studying species composition, density, diversity and regeneration status of woody species and soil seed banks in enclosures and adjacent open areas at two widely separated sites known as Biyo–Kelala and Tiya in central and northern Ethiopia, respectively. Fifty-eight woody species, representing 30 plant families, were recorded at Biyo–Kelala, of which only 25 were recorded both in the enclosure and open area while two were recorded outside of the sample plots. At Tiya, 31 woody species, representing 19 families, were recorded in the enclosure but only 15 of these species were encountered in the open area. Woody plant densities were 1746 and 2215 individuals/ha in the enclosure and open area at Biyo–Kelala, respectively, and 3705 and 3048 individuals/ha in the enclosure and open area at Tiya, respectively. *Dodonaea angustifolia* and *Acacia etbaica* were the most dominant species at Biyo–Kelala and Tiya, respectively. The enclosure at Biyo–Kelala had about twice the diversity value of the open area, while the corresponding values were 2.5 and 2 for the enclosure and open area at Tiya, respectively. The total numbers of species recovered from the soil samples collected in Biyo–Kelala site were 48 for the enclosure and 30 for the open area with mean seed densities of 2765 ($\pm$124) and 1663 ($\pm$117) seeds m^2, respectively. At Tiya, 30 and 16 species were recovered in the enclosure and open area, respectively, with mean seed densities of 2811 ($\pm$276) and 996 ($\pm$243) seeds m^2, respectively. The diversity of all plant species in the soil seed bank was greater in the enclosure

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than the open area at both sites. Herbs and grasses dominated the soil seed banks at both sites while several of the woody species recorded in the above-ground vegetation were not represented at all. Overall results from this study indicate strongly that establishment of enclosures is very advantageous over other methods since it is a fast, cheap and lenient method for the rehabilitation of degraded lands.

Keywords: Species composition; Density; Diversity; Diameter class; Population structure; Regeneration; Soil seed banks

1. Introduction

The present estimated area of drylands in Ethiopia is over 75 million ha, about 66% of the total area of the country (Anonymous, 2000; EFAP, 1994). Of this, 25 million ha is covered with woodlands and bushlands. This implies that the largest vegetation resource of the country is found in the dryland areas. These enormous areas of dryland vegetation resources are facing serious problems of degradation. This has been attributed to the fact that land has been used as a mine, rather than a renewable resource, for centuries in the country (Tewolde, 1989). Vegetation resources, particularly the woody plants, in these areas are declining both in quantity due to deforestation and quality as a result of degradation. The main causes of the degradation have been cutting of woody plants for various purposes, e.g. clearing the vegetation, usually involving fire, for producing crops spurred by the ever-increasing human population. To minimize or avoid the current and potential undesirable consequences, proper attention must be given to the dryland areas in the country.

The prolonged degradation of dryland areas continues to affect the productivity and genetic diversity of forest, woodland and bushland resources. Exacerbated by the recurrent drought, the ultimate outcome of deforestation and degradation of these resources may be desertification. Sustainable conservation and utilization of the remaining dryland vegetation resources and rehabilitation of those that have already been degraded would provide economic, social and ecological benefits. This requires designing economically feasible, socially acceptable and ecologically viable management and conservation strategies of dryland vegetation.

In this regard, the practice of establishing enclosures has emerged as a promising practice in different parts of Ethiopia (Bendz, 1986), namely in Tigray (Kindeya, 1997; Mitiku and Kindeya, 2001; Emiru, 2002; Kidane, 2002; Tesfaye, 2002), Welo (Kebrom, 1998; Tefera, 2001) and Shewa (Tefera, 2001). Enclosures are areas selected for natural regeneration of the native flora as a means of land reclamation through protection of the areas from human and animal interference (Bendz, 1986; Alemneh, 1992). Since the objective of most enclosures is for site rehabilitation/reclamation, they are usually established in steep, eroded and degraded areas used for grazing and crop production in the past (Bendz, 1986). The practice of enclosure has been traditionally exercised for centuries around church boundaries in Ethiopia by restricting the use of forests around churches as prestige for the religious sites (Alemayehu, 2002). Plant and animal diversity in enclosures increases with time after establishment (Bendz, 1986; Kindeya, 1997; Mitiku and Kindeya, 2001; Emiru, 2002; Kidane, 2002; Tesfaye, 2002). Hence, establishment of enclosures has been recognized as a promising method in the rehabilitation of degraded areas, particularly, in Northern Ethiopia where degradation of natural resources has been considerably higher than in other parts of the country. Where they had been established, enclosures are among the green spots with considerable species diversity (Tefera, 2001; Emiru, 2002).

The local people have reported that species that disappeared long time ago have been restored following establishment of enclosures. For instance, species that could not be observed for many years in some parts of eastern Tigray, namely *Olea europaea* subsp. *cuspidata* and *Juniperus procera*, reappeared, densities and diversities of the flora, particularly of grasses, and fauna increased, soil erosion decreased and even dead springs started to flow after different enclosures were established (Emiru, 2002). As a result, enclosures are becoming promising assets as sources of not only biomass energy, which accounts for about 80% of the total household energy supply in the country (EFAP, 1994), but also wood for construction, agricultural implements and several other purposes. Non-timber forest products, e.g. grass for feed and thatching, are becoming important outcomes of enclosures. Encouraged by these results, efforts are underway currently to replenish denuded areas of northern Ethiopia through the establishment of enclosures to promote conservation-based sustainable agriculture along with maintaining and enhancing the biodiversity of drylands (Kindeya, 1997; Emiru, 2002).

Despite the emerging and promising socio-economic and ecological importance of enclosures in Ethiopia, very little or virtually no systematic and scientific studies have been made about enclosures. As a result, documented information on enclosures is scanty or completely lacking. Therefore, studies aimed at generating empirical information on history, diversity of the flora, fauna and micro-organisms before and after establishment, rates and processes involved in recovery or dynamics of the vegetation, etc., which would ultimately assist to make informed decisions on the future fates of enclosures. In particular, such information is crucial for developing strategies, programs or technical guidelines for their conservation and sustainable utilization.

Therefore, this study was initiated as a step towards understanding the actual and potential contribution of enclosures in the recovery of woody vegetation on degraded drylands. Specifically, the objectives of the study were to: (i) investigate the species composition, density and diversity of both the above-ground component of woody plants and soil seed banks; (ii) determine the regeneration status of some selected woody plants; (iii) compare the similarity of species composition of woody plants between enclosures and open areas as well as the standing vegetation and soil seed banks at two distantly located study sites in central and northern Ethiopia.

2. Materials and methods

2.1. Study sites

This study was conducted at two different sites, Biyo–Kelala and Tiya, in the central and northern parts of Ethiopia, respectively. The former is located in the Awash River Catchment Area while the latter is found in the Tekeze River Catchment Area (Tefera, 2001). These sites were selected since they are the oldest enclosures in their respective areas, i.e. central and northern Ethiopia.

2.1.1. Biyo–Kelala site

Biyo–Kelala site is located at about 8°35′–8°40′N and 39°00′–39°05′E and about 62 km east of Addis Abeba. The area is generally characterized by moderately plain area with scattered mountains and hills. For the present study, two hilly areas, Biyo (64 ha) and Kelala (24 ha) were selected. Similar to hilly areas in other parts of the country, many decades of cutting woody plants and uncontrolled grazing left these hills devoid of vegetation. In 1979, Biyo and Kelala hills were planted, as part of the plantation campaign launched by the Government, mainly with exotic trees, and protected (enclosed) against any disturbance by humans and livestock. Since then, Biyo hill (hereafter referred to as "Biyo–Kelala enclosure"), is under continuous protection while the woody vegetation that developed at Kelala hill (hereafter referred to as "Biyo–Kelala open area"), was almost completely destroyed by grazing and cutting.

Biyo and Kelala sites have an altitude ranging between 1880 and 1960 m with the slope ranging between 2% and 35%. The site falls within the lava plateau of the Rift margin and is dominated by sandy loam, heavy clay and clay loam soils. The majority of people in the areas are engaged in crop production and sedentary livestock rearing. Crop production is mainly rainfed. Farming is mainly by oxen and rarely by farm tractors. The area receives an annual minimum and maximum rainfall of 604 and 1044 mm, respectively, while the average temperature of the area is about 28°C. The dry season in the area extends from October to May and the wet season covers the period between June and September.

The vegetation in the area has been categorized under the "Semi-arid woodland with broad-leaved species" (Aalbaek, 1993). This vegetation type is characterized by several species of *Acacia* (*A. abyssinica, A. albida, A. seyal, A. tortilis,* etc.), *Balanites aegyptiaca, Combretum molle, Croton macrostachyus, Dodonaea angustifolia, Erythrina abyssinica, Euphorbia candelabrum, Olea europaea* subsp. *cuspidata*, etc. (Aalbaek, 1993).

2.1.2. Tiya site

Tiya is located at about 12°31′–12°32′N and 39°03′–39°05′E and about 720 km north of Addis Abeba. The study site has rugged topography dominated by rock outcrops with mountainous terrain and high plateaus dissected by river basins. Due to its rugged topography, it is one of the areas with the highest rate of soil erosion in the country.

Land degradation is a typical phenomenon of the area, which is supposed to have been caused by over exploitation of the woodlands and farming of the fragile hill slopes. The expansion of agriculture, especially towards the steeper slopes of the mountains resulted in the clearing of forests for centuries. This in turn has accelerated soil erosion and destroyed the soil and vegetation of the area. The woodlands have been and still are the major sources of wood for fuel and construction.

For the present study, two areas were selected at the Tiya hill, one of which, hereafter referred to as "Tiya enclosure" (45 ha), has been under protection (with enclosure) since 1995, regenerating with pioneer species. The other area, hereafter referred to as "Tiya open area" (18 ha), has been under free common grazing. The altitude and slope at Tiya site range between 2100 and 2200 m and 03% and 50%, respectively. Sedentary mixed farmers occupy the study area. They depend on crop production and animal rearing for their livelihood, both of which are constrained by recurrent drought.

The annual rainfall, recorded between 1997 and 2000, ranged between 349 and 643 mm for Sekota. The rainfall is concentrated in the months between June and August while the remaining nine months are apparently dry. Tiya is an area that can be classified as a high soil degradation-risk zone. The soil is generally dominated by infertile, coarse textured and sandy soils.

The vegetation in the area has been categorized under the *Juniperus*/*Olea* Forest within Welo Dry *Juniperus* Forest Seed Zone (Aalbaek, 1993). Broad-leaved species are dominating whereby the family Fabaceae is a significant contributor to the biomass of the area. Several species of *Acacia* (*A. abyssinica, A. albida, A. seyal, A. tortilis,* etc.), *Albizia gummifera, Celtis africana, Cordia africana, Croton macrostachyus, Dodonaea angustifolia, Ekebergia capensis, Erythrina abyssinica, Euphorbia candelabrum, Hagenia abyssinica, Juniperus procera, Olea europaea* subsp. *cuspidata*, etc. are dominating (Aalbaek, 1993). The vegetation around the site could be categorized under dry *Acacia*-dominated Afromontane forest (Friis, 1992; Kebrom, 1998).

2.2. Methods

Since the study was made many years after the establishment of enclosures, it was not possible to fully explain the process in the vegetation dynamics. But changes after the establishment of enclosures could be described using some important parameters such as plant cover, species diversity, biomass productivity and chemical constituents of the soil in the areas (Kebrom, 1998) compared with the adjacent open lands. The assumption in this study is that the enclosures and open areas had similar conditions before establishment of the enclosures.

2.2.1. Composition and density of woody plants

To determine the composition and density of woody plants, parallel line transects, which were 200 m apart from each other, were laid crossing the study sites from west to east direction. Along each transect, sample quadrats measuring 20 m × 20 m (400 m^2) were laid down at 50 m intervals. In each of these quadrats, the identity and number of all individuals of woody species were determined and recorded. For plants, which could not be identified in the field, herbarium specimens were collected, properly dried in a plant press, and identified at the National Herbarium in Addis Abeba University, where voucher specimens were deposited.

A total of 70 quadrat plots were examined at Biyo–Kelala site, of which 44 quadrat plots were inside the enclosure and 26 in the open area. Similarly, a total of 45 plots were examined at Tiya site, of which 28 plots were inside the enclosure and the remaining 17 were in the open area. Since the open areas were devoid of vegetation and spatially less heterogeneous compared to the enclosures, fewer quadrats were taken. In this study plant nomenclature follows Cufodontis (1953–1972), Hedberg and Edwards (1989, 1995), Friis (1992), Edwards et al. (1995, 1997, 2000) and Hedberg et al. (1995).

2.2.2. Population structure of woody plants

Population structure has been used widely to examine the regeneration status of woody plants (Silvertown, 1982; Tamrat, 1994; Demel, 1997a; Mekuria et al., 1999; Tadesse et al., 2000; Feyera et al., 2002). Hence, to assess the population structure of woody plants, the diameters and heights of individuals of woody species encountered in the sample quadrats were measured using diameter tape and graduated wooden rod or hypsometer in suitable cases, respectively. In order to determine the height at which diameter measurement should be taken, branching heights of sample trees were measured first, from which the average height was determined for diameter measurement as diameter at determined height (DDH). Accordingly, the diameter measurement was taken at 0.5 and 0.7 m height for Tiya and Biyo–Kelala sites, respectively. For saplings, the diameter measurement was taken above the soil surface (basal stem diameter). For seedlings with heights less than 0.5 m, only their number was counted.

2.2.3. Soil seed banks

To investigate the composition, density and spatial distribution of the soil seed banks, five plots each measuring 15×15 cm (225 cm^2) were marked at the center and four corners of the sample quadrats used for investigating the composition and density of woody plants. From these plots, four separate soil layers were removed using a sharp knife and put in plastic bags. These layers include the top 3 cm layer (including the litter layer) and three successively deeper mineral soil layers each three centimeters thick. The samples were taken carefully so as not to contaminate the deeper soil layers with the upper ones. The soil layers sampled from similar layers of the five plots in each quadrat were mixed thoroughly to make a composite sample aimed at minimizing the variability within the quadrat. The composite sample for each soil layer was again divided into five equal parts from which one was selected randomly as a working soil sample. The total numbers of sample soil layers were 280 (4 layers $\times$ 70 quadrats) at Biyo–Kelala and 180 (4 layers $\times$ 45 quadrats) at Tiya sites. The soil samples were transported to the National Tree Seed Project (NTSP) Seed Laboratory located in the premises of the Forestry Research Centre (FRC) in Addis Abeba for recovering seeds.

The methods used to recover seeds from the soil samples were sieving and seedling emergence or germination technique. In the laboratory, the soil samples were passed through a sieve having mesh-sizes ranging between one and 2.5 mm, and seeds encountered in the process were identified at species or genus level using local identification manuals, and their viability was determined by cutting test (Demel and Granström, 1995, 1997). Those seeds that were difficult to identify were recorded as unidentified species.

Immediately after sieving, the soil samples were transported to a glasshouse located in the compound of the Ethiopian Agricultural Research Organization (EARO) Headquarters in Addis Abeba. In the glasshouse, each soil layer was spread inside a circular plastic tray having 15 cm top and 10 cm bottom diameters and watered daily to stimulate the germination of seeds that were not captured in the sieving process. To facilitate proper drainage of water, the trays were perforated at the bottom. To avoid disappearance of small seeds through the perforations, the bottom part of the tray was covered by cotton cloth. Just after a week of incubation, seedlings started to emerge from the soil samples. The emerging seedlings were identified, counted, recorded and finally carefully uprooted and discarded. The soil samples were carefully stirred to bring deeply located seeds to the surface for germination. For those that were difficult to identify at the regeneration stage, up to three seedlings were transplanted in pots and observed until they could be identified. Taxa that could not be reliably identified to species level were simply recorded to their genus level. The observation was terminated after 8 months of incubation.

2.3. Data processing and analyses

The density of each woody plant per hectare was derived from the total number of individuals recorded in the 44 quadrats (1.76 ha) and 26 quadrats (1.04 ha) at the enclosed and open hills, respectively, of Biyo–Kelala site. Similar analysis was made for the 28 quadrats (1.12 ha) and 17 quadrats (0.68 ha) at the enclosed and open hills of Tiya site, respectively. The species diversities in both land use types and in both study sites as well as diversity in each diameter class were calculated using Shannon–Wiener Index (H) (Magurran, 1988). The similarity between the enclosure and open areas in their standing vegetation and the soil seed bank were analysed using Sørenson's Similarity Coefficient (SSC) (Krebs, 1989; Tamrat, 1994).

The composition, density and spatial distribution of seeds in the soil, was determined by combining the sieving and germination data. The density of seeds per square meter was derived from the total number of seeds recovered from the samples. On the other hand, the depth distribution of seeds at each of the hills in the two sites, was calculated from the combined number of seeds recovered in similar layers and was converted to provide the density of seeds per square meter at that particular soil depth.

3. Results

3.1. Composition of above-ground woody vegetation

A total of 58 woody species representing at least 30 plant families were recorded at the Biyo–Kelala site, of which 25 were recorded both in the enclosure and open area while only two were recorded outside of the sample plots (Table 1). Five of the woody species in the enclosure and two species in the open area were planted exotic species. Among the species encountered, 25 were recorded both in the enclosure and open areas. The family Fabaceae was represented by 14 species (25%) inside the enclosure followed by Loranthaceae and Euphorbiaceae, which had five (8.9%) and four (7.1%) species, respectively. In the open area, Fabaceae was represented by seven species (27%) followed by Oleaceae containing only two species. Similarly, a total of 31 woody species, representing at least 19 families, were recorded in Tiya site of which all were recorded in the enclosure and 15 of them in the open area (Table 2). Sixteen species (51%) were found exclusively in the enclosure, of which two were planted exotic species. In the enclosure, the family with the highest number of species was Fabaceae, represented by six species, followed by Tiliaceae, Oleaceae and Anacardiaceae, which were represented by two species each. The remaining 14 families were represented by only one species each. For the open area, the family with the highest number of species was also Fabaceae, represented by four species, while the remaining families were represented by only one species each except Oleaceae, which was represented by two species.

3.2. Density of woody plants

The densities of all woody plants in the enclosure and open area at Biyo–Kelala site were 1746 and 2215 individuals/ha, respectively (Table 1). The pioneer species, *Dodonaea anguistifolia*, was the most dominant species in the enclosure followed by *Grewia ferruginea, A. abyssinica, A. seyal, A. etbaica* and *A. tortilis*. Some woody plants, e.g. *Stereospermum kunthianum,* were observed in the enclosure although they were not encountered in the sample quadrats. On the other hand, *Echinops macrochaetus* that accounted for 62% of the density of woody plants dominated the open area followed by *Sida alba,* another woody herb (Table 2). Similarly, the densities of all woody plants in the enclosure and open area of Tiya site were 3705 and 3048 individuals/ha, respectively. *A. etbaica* was the most abundant species in both land uses followed by *Euclea* (Tables 1 and 2).

3.3. Population structure of woody plants

Of the total density of all woody species, the proportions of seedlings, saplings and trees in the enclosure at Biyo–Kelala were 72%, 14%, and 14%, respectively. However, the proportions of trees and saplings for the open area were negligible. At Biyo–Kelala, two groups of species could be differentiated from the structural analyses: Group I—represented by species that exhibited a pattern with the highest proportion of individuals being lower than 2.5 cm in diameter, showing a sign of active regeneration; e.g. *A. seyal, Dodonaea anguistifolia* and *Grewia ferruginea;* and Group II—represented by species, which exhibited affected population structures, i.e. few or missing individuals at one or more diameter classes; e.g. *A. tortilis, A. sieberiana* and *Croton macrostachyus* (Fig. 1). Outside these groups, species with one or less than one tree/ha were also encountered.

Table 1
List of woody species recorded at Biyo–Kelala site with their densities and frequencies

Species[a]	Life-form	Enclosure		Open area	
		Density[b]	Frequency[c]	Density	Frequency
Dodonaea angustifolia	Shrub	263	50	189	73
A. saligna[d]	Shrub/tree	183	52	3	4
Grewia ferruginea	Shrub/tree	175	81	32	58
A. abyssinica	Tree	171	50	42	8
A. seyal	Tree	141	38	1	12
A. etbaica	Tree	122	72	53	73
A. tortilis	Tree	103	68	1	4
Clerodendrum myricoides	Tree	77	61	3	4
Croton macrostachyus	Tree	64	63	32	50
Echinops macrochaetus	Shrub	64	67	1368	100
Ocimum urticifolium	Shrub	50	43	—	—
Eucalyptus camaldulensis[d]	Tree	36	30	8	15
Jasminum abyssinicum	Woody climber	31	50	79	65
Not identified	Shrub	30	61	4	12
Leucaena leucocephala[d]	Shrub/tree	28	41	—	—
Rhus vulgaris	Shrub/tree	24	39	18	42
Justicia schimperiana	Shrub	21	18	—	—
Buddleja polystachya	Tree	19	20	—	—
Pterollobium stellatum	Woody climber	19	0.5	—	—
Euphorbia tirucalli	Bush	15	7	—	—
A. sieberiana	Tree	15	34	—	—
Combretum collinum	Tree	13	7	—	—
Asparagus africanus	Woody climber	10	30	7	73
Dichrostachys cinerea	Shrub/tree	10	32	—	—
Not identified	Bush	8	5	—	—
Casuarina equisetifolia[d]	Tree	7	16	—	—
Tragia cinerea	Woody climber	7	7	—	—
Not identified	Tree	5	9	—	—
Tapinanthus globiferus	Woody-parasite	4.5	4	—	—
Maytenus arbutifolia	Shrub/tree	4	9	16	27
Helinus mystacinus	Woody climber	4	5	3	4
Schinus molle[d]	Tree	2	0.5	—	—
Euphorbia candelabrum	Tree	2	5	—	—
Capparis tomentosa	Shrub	2	2	2	8
Withania somnifera	Tree	2	9	43	12
Carissa spinarum	Shrub/climb	2	9	15	31
Calpurnia aurea	Shrub	1	4.5	43	35
Tephrosia emeroides	Woody herb	1	2	—	—
Ehretia cymosa	Tree	1	5	3	4
Ficus sycomorus	Tree	1	2	—	—
A. albida	Tree	1	5	1	4
Celtis africana	Tree	1	2	—	—
Acacia sp.	Tree	0.5	2	4	8
Olea europaea subsp. *cuspidata*	Tree	0.5	2	1	4
Euclea racemosa subsp. *schimperi*	Bush/tree	—	—	42	19
Sida alba	Woody herb	—	—	202	58
Total		1746		2215	

[a] Plant nomenclature follows Cufodontis (1953–1972), Hedberg and Edwards (1989), Friis (1992), Edwards et al. (1995, 1997, 2000) and Hedberg et al. (1995).

[b] Only species with one or more tree/ha included; species arranged in descending order of their density, i.e. the number of individuals/ha.

[c] Proportion of quadrates (%) in which the species was found.

[d] Planted species.

Table 2
List of woody species recorded at Tiya study site with their densities and frequencies

Species[a]	Life-form	Enclosure		Open area	
		Density[b]	Frequency[c]	Density	Frequency
A. etbaica	Tree	1275	100	665	10
Euclea racemosa subsp. *schimperi*	Bush/tree	625	100	575	76
Rhus natalensis	Shrub	325	96	325	88
A. tortilis	Tree	200	82	125	23
Maytenus arbutifolia	Shrub/tree	200	75	524	94
Oromocarpum trichocarpum	Shrub	184	46	50	17
Dichrostachys cinerea	Shrub/tree	175	46	—	—
Jasminum abyssinicum	Woody climber	146	78	350	64
Becium grandiflorum	Shrub	146	17	175	17
Dodonaea angustifolia	Shrub	69	50	25	23
A. saligna[d]	Shrub/tree	57	28	—	—
Euphorbia candelabrum	Tree	49	28	25	29
Not identified	Shrub	30	42	—	—
Senna singueana	Shrub/tree	30	57	100	58
Carissa spinarum	Shrub/climb	32	39	—	—
Stereospermum Kunthianum	Tree	32	4	—	—
Commiphora habessinica	Tree/shrub	30	39	—	—
Olea europaea subsp. *cuspidata*	Tree	26	32	9	23
Not identified	Tree	13	25	25	11
Boscia salicifolia	Tree	12	32	—	—
Steganotaenia araliacea	Shrub/tree	12	7	—	—
Grewia ferruginea	Shrub/tree	8	32	50	6
Asparagus africanus	Woody climber	5	7	—	—
Grewia erythraea	Shrub	5	4	—	—
Leucaena leucocephala[d]	Shrub/tree	4	7	—	—
Buddleja polystachya	Tree	4	17	25	11
Lannea fruticosa	Tree	4	3	—	—
Pterollobium stellatum	Woody climber	2	3	—	—
Pavetta gardeniifolia	Shrub	2	3	—	—
Osyris quadripartita	Tree/shrub	1	3	—	—
Total		3705		3048	

[a] Plant nomenclature follows Cufodontis (1953–1972), Hedberg and Edwards (1989), Friis (1992), Edwards et al. (1995, 1997, 2000).

[b] Species arranged in descending order of their density, i.e. the number of individuals/ha; Number of individuals/ha.

[c] Proportion of quadrates (%) in which the species was found.

[d] Planted species.

At Tiya site, of the total densities of all woody species, seedlings, saplings and trees accounted for 61%, 20% and 19%, respectively, in the enclosure and 59%, 21% and 20%, respectively, in the open area. The two groups of species recognized in Biyo–Kelala based on their population structures were also encountered in Tiya: Group I—represented by species with high number of individuals in the lower size classes with a more or less inverted "J" shaped frequency distribution of the diameter

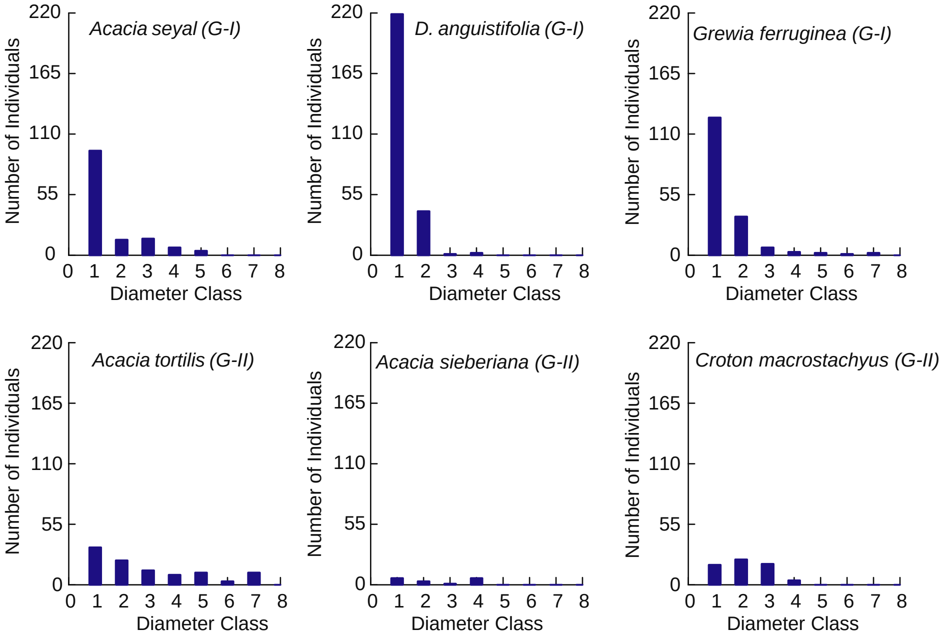

Fig. 1. Population structure of some woody species in the enclosure at Biyo–Kelala site (G-I = Group I and G-II = Group II; Diameter classes: 1 = <2.5 cm; 2 = 2.5–5.5 cm; 3 = 5.5–7.5 cm; 4 = 7.5–10; 5 = 10–12.5 cm; 6 = 12.5–15 cm; and 7 = >15 cm).

classes, which indicates good regeneration status; e.g. *A. etbaica, Euclea racemosa* subsp. *schimperiana* and *Rhus natalensis* in the enclosure and *Euclea racemosa* subsp. *schimperiana* in the open area; Group II—represented by species, which exhibited affected population structures, i.e. few or missing individuals at one or more diameter classes; e.g. *A. tortilis* in the enclosure as well as *A. etbaica, A. tortilis* and *Rhus natalensis* in the open area (Fig. 2).

3.4. Diversity of woody plants

Considering only the naturally regenerated woody plants at Biyo–Kelala site, the enclosure had about twice ($H = 2.7$) the diversity value of the open area ($H = 1.5$). The diversity distribution of the species with diameter classes revealed a higher diversity value for the enclosure than the open area (Fig. 3). The open area had diversity value exclusively for the first diameter class only. The other diameter classes had either no species composition or were represented by only one species for which the diversity value will not be depicted. Shannon–Wiener Indices were 2.5 and 2 for the enclosure and open area at Tiya site, respectively. Comparison of Shannon's Diversity Index for the different diameter classes revealed higher values for the enclosure than the open area at each class. However, in both cases the smaller diameter classes exhibited higher diversity values than the larger classes.

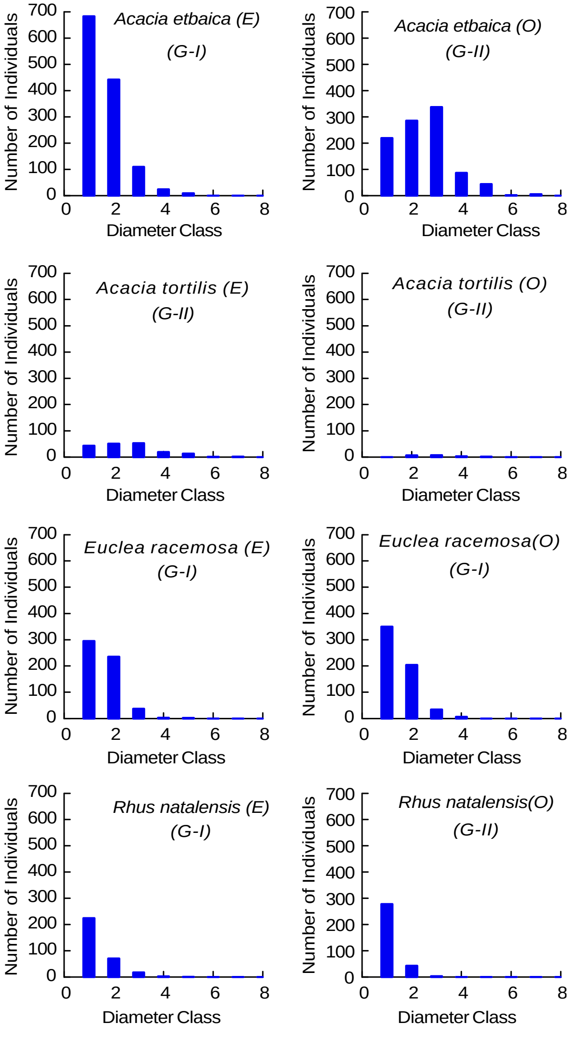

Fig. 2. Population structure of some woody species in the enclosure and open area at Tiya site (G-I = Group I and G-II = Group II; Diameter classes: 1 = <2.5 cm; 2 = 2.5–5.5 cm; 3 = 5.5–7.5 cm; 4 = 7.5–10; 5 = 10–12.5 cm; 6 = 12.5–15 cm; and 7 = >15 cm; E = enclosure; O = open area).

3.5. Composition and density of soil seed banks

The total numbers of species recovered from the soil samples collected in Biyo–Kelala site were 48 for the enclosure and 30 for the open area (Table 3). Of these, at least 11 species of the enclosure and 4 species of the open area were woody species while the rest were herbs and grasses. The total numbers of seeds obtained from all soil samples collected down to the depth of 12 cm in the enclosure (total area of

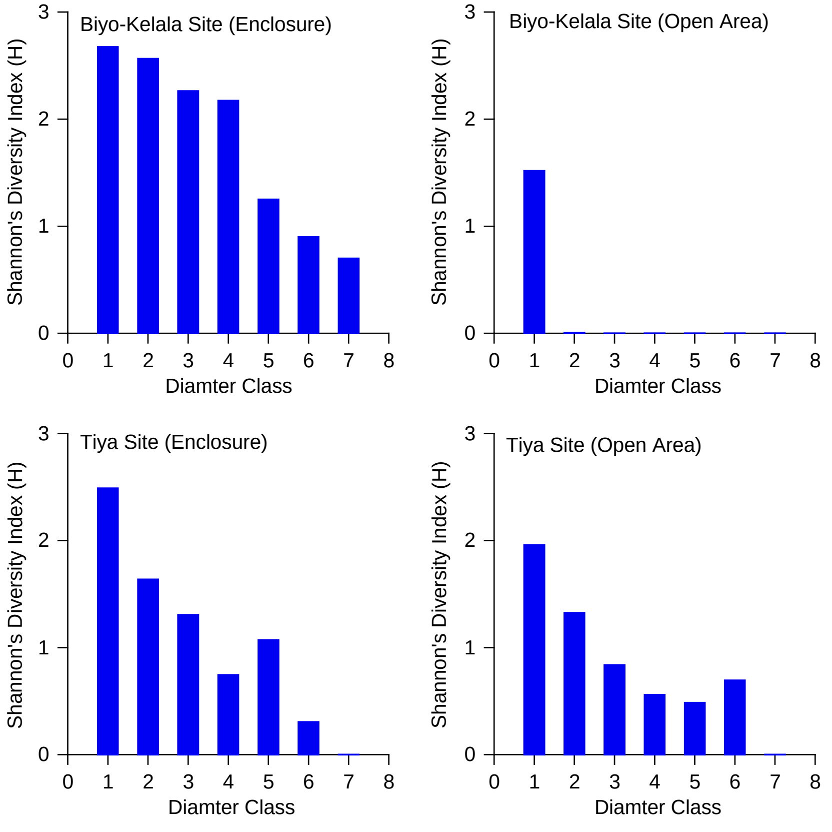

Fig. 3. Diversity of woody plants in each diameter class at the two sites (diameter classes: 1 = <2.5 cm; 2 = 2.5–5.5 cm; 3 = 5.5–7.5 cm; 4 = 7.5–10; 5 = 10–12.5 cm; 6 = 12.5–15 cm; and 7 = > 15 cm).

samples = 9900 cm^2) and open area (total area of samples = 5850 cm^2) at Biyo–Kelala were 2737 and 973, respectively. These corresponded to mean densities (±S.E.) of 2765 (±124) and 1663 (±117) seeds m^{-2}, respectively. Similarly, at Tiya site, a total of 30 and 16 species were recovered from all the soil samples collected in the enclosure and open area, respectively (Table 4). The total numbers of seeds obtained from all soil samples collected down to the depth of 12 cm in the enclosure (total area of samples = 6300 cm^2) and the open area (total area of samples = 3825 cm^2) at Tiya were 1771 and 381, respectively. The corresponding mean densities (±S.E.) were 2811 (±276) seeds m^{-2} in the enclosure and 996 (±243) seeds m^2 in the open area.

The highest densities of seeds were observed in the upper three centimeters of soil in both the enclosures and open areas at both sites and seed density decreased with increasing depth (Fig. 4). The number of species present showed a similar but less pronounced trend (Fig. 5). There was variation in the depth distribution of seeds and species both between species and between the enclosures and open areas at both sites (Table 3 and 4; Figs. 4 and 5).

Table 3
List of species with the number of seeds recorded from the soil samples collected at the Biyo–Kelala site

Species[a]	Life-form	Enclosure					Open area				
		Total	Soil layer				Total	Soil layer			
			1	2	3	4		1	2	3	4
Andropogon abyssinicus[b]	Grass	621	313	159	109	40	322	126	95	46	55
A. saligna	Shrub	543	267	168	70	38	20	8	8	2	2
Kohautia coccinia	Herb	318	141	95	49	33	378	104	142	89	43
Tagetis minuta	Herb	193	111	43	20	19	—	—	—	—	—
Cyperus sp. 1	Sedge	162	98	35	21	8	33	15	4	7	7
Amaranthus greacizanus	Herb	40	22	13	4	1	5	3	—	2	—
Bromus leptoclodos	Grass	137	78	33	19	7	56	37	11	6	2
Galinsoga quadriradiata	Herb	130	70	27	19	14	1	1	—	—	—
Bidens negriana	Herb	102	51	30	12	9	15	14	1	—	—
Macrotyloma tenuiflorum	Herb	59	27	17	7	8	8	4	3	1	—
Not identified	—	53	25	11	14	3	1	1	—	—	—
Dodonaea angustifolia	Shrub	40	31	9	—	—	11	5	4	1	1
Solanum nigrum	Herb	33	11	7	8	7	19	4	5	2	8
Trifolium baccarinii	Herb	27	14	8	4	1	5	3	1	1	—
Senecio ochrocarpus	Herb	26	21	5	—	—	8	5	3	—	—
Achyranthus aspera	Herb	23	11	5	4	3	—	—	—	—	—
Digitaria velutina	Grass	21	14	4	1	2	21	7	3	6	5
Setaria verticillata	Grass	18	15	2	1	—	1	—	1	—	—
Arthraxon lancifolius	Herb	17	13	3	1	—	9	8	1	—	—
Bidens pilosa	Herb	17	7	4	3	3	—	—	—	—	—
A. seyal	Tree	15	14	—	1	—	—	—	—	—	—
Oxalis radicosa	Herb	15	8	4	1	2	7	—	4	3	—
Erucastrum arabicum	Herb	12	4	7	1	—	5	2	1	2	—
Nephrophyllum abyssinicum	Herb	12	8	2	1	1	—	—	—	—	—
Datura stramonium	Herb	11	10	—	1	—	—	—	—	—	—
Eragrostis tef	Grass	11	7	—	4	—	2	2	—	—	—
Not identified	Herb	10	6	4	—	—	—	—	—	—	—
A. tortilis	Tree	9	8	—	1	—	—	—	—	—	—
Astragalus fetmensis	Herb	7	1	1	3	2	4	—	1	1	2
Eucalyptus camaldulensis	Tree	6	1	2	2	1	2	—	—	—	2
Grewia ferrugenia	Tree	5	5	—	—	—	—	—	—	—	—
Not identified	—	5	—	3	2	—	5	1	2	1	1
Acacia sp. 1	Tree	4	3	—	1	—	—	—	—	—	—
Croton macrostachyus	Tree	4	1	1	2	—	—	—	—	—	—
Ocimum urticifolium	Shrub	4	4	—	—	—	—	—	—	—	—
Misopates orontium	—	3	3	—	—	—	9	—	1	3	5
Satureja abyssinica	Herb	3	3	—	—	—	—	—	—	—	—
Solanum villosum	Herb	3	—	—	3	—	—	—	—	—	—
Not identified	—	3	3	—	—	—	19	—	1	5	13
A. etbaica	Tree	2	1	—	—	1	—	—	—	—	—
Chenopodium album	Herb	2	1	1	—	—	—	—	—	—	—
Commelina africana	Herb	2	2	—	—	—	—	—	—	—	—
Commelina subulata	Herb	2	2	—	—	—	—	—	—	—	—
Zaleya Pentandra	Herb	2	1	—	1	—	—	—	—	—	—
Not identified	Herb	2	2	—	—	—	—	—	—	—	—
Acacia sp. 2	Tree	1	—	1	—	—	—	—	—	—	—

Table 3 (*continued*)

Species[a]	Life-form	Enclosure					Open area				
		Total	Soil layer				Total	Soil layer			
			1	2	3	4		1	2	3	4
Launaea massauensis	Herb	1	1	—	—	—	1	1	—	—	—
Not identified	—	1	—	—	1	—	2	—	1	—	1
Not identified	—	—	—	—	—	—	2	2	—	—	—
Caylusea abyssinica	Herb	—	—	—	—	—	1	—	1	—	—
Kohautia aspera	Herb	—	—	—	—	—	1	1	—	—	—
Total		2737	1439	704	391	203	973	354	294	178	147

[a] Plant nomenclature follows Cufodontis (1953–1972), Hedberg and Edwards (1989, 1995), Friis (1992), Edwards et al. (1995, 1997, 2000).

[b] Species arranged with descending total number of seeds.

3.6. Diversity of the soil seed banks

Acacia saligna, one of the planted exotic trees, accounted for 72% of the woody portion of the soil seed bank, 20% of the total soil seed bank in the enclosure and only 2% of the soil seed bank in the open area at Biyo–Kelala site (Table 3). Even though, the diversity of all plant species, including herbs and grasses, in the soil seed bank was greater in the enclosure ($H=3$) than the open area ($H=1.6$) at Biyo–Kelala site, it seems to have a decreasing trend with depth for both land uses (Fig. 4). Similarly, the diversity of soil seed banks at Tiya site was 1.77 for the enclosure and 1.48 for the open area. Herbs and grasses dominated the soil seed banks at both sites while several of the woody species recorded in the above-ground vegetation were not represented at all (compare Table 1 with Table 3 and Table 2 with Table 4).

3.7. Similarity between the enclosures and open areas

There were considerable differences in the species composition of the above-ground woody vegetation between the enclosures and open areas at both sites (SSC = 0.60 and 0.65 for Biyo–Kelala and Tiya sites, respectively). Similar differences were also observed in the species composition of the soil seed banks between the enclosures and open areas at both sites (SSC = 0.60 and 0.66 for Biyo–Kelala and Tiya sites, respectively). Comparisons of the compositions of woody species between the above-ground vegetation and the soil seed bank revealed quite low similarities for the enclosures at both sites (SSC = 0.31 and 0.06 for Biyo–Kelala and Tiya sites, respectively) and the open area at Biyo–Kelala site (SSC = 0.15). For the open area at Tiya site, similarity of the composition of woody species between the standing vegetation and the soil seed bank could not be calculated since woody species were not represented in the soil seed bank.

Table 4
List of species with the number of seeds recorded from the soil samples collected at Tiya site

Species[a]	Life-form	Enclosure					Open area				
		Total*	Soil layers				Total	Soil layers			
			1	2	3	4		1	2	3	4
Cyperus sp 2.	Sedge	962	702	174	56	30	499	355	70	50	24
Aristida congesta	Herb	153	118	20	10	5	—	—	—	—	—
Cyperus rotundus	Grass	134	103	23	2	6	137	98	22	13	4
Eragrostis aspera	Grass	129	60	34	25	10	121	81	29	7	4
Ocimum basilicum	Herb	121	79	19	12	11	10	6	2	2	—
Chloris pyconothrix	Grass	85	61	13	7	4	45	28	14	1	2
Tragus berteronianus	Herb	37	31	5	1	—	27	18	5	1	3
Medicago sativa	Herb	29	17	3	4	5	5	3	1	—	1
Ochthochloa compressa	Grass	17	9	5	1	2	9	9	—	—	—
Bidens macropetra	Herb	16	13	1	1	1	4	1	2	1	—
Phylanthus fischeri	Herb	16	11	—	5	—	—	—	—	—	—
Pilea tetraphylla	Herb	12	7	—	4	1	—	—	—	—	—
Eragrostis tef	Grass	8	—	6	—	2	10	7	2	—	1
Brachypodium distachyon	Herb	7	7	—	—	—	—	—	—	—	—
Senecio ochrocarpus	Herb	7	3	2	1	1	2	2	—	—	—
Tephrosia pentaphylla	Herb	7	5	1	—	1	2	1	—	—	1
Festuca abyssinica	—	6	5	—	1	—	—	—	—	—	—
Setaria verticillata	Grass	6	4	1	1	—	1	1	—	—	—
Launaea intybacea	Herb	4	4	—	—	—	—	—	—	—	—
Barleria argentia	Herb	2	2	—	—	—	—	—	—	—	—
Tephrosia emeroides	Herb	2	2	—	—	—	—	—	—	—	—
Not identified	—	2	1	1	—	—	3	2	—	1	—
Not identified	—	2	1	1	—	—	—	—	—	—	—
Acacia sp.	Wood	1	1	—	—	—	—	—	—	—	—
Achyranthus aspera	Herb	1	1	—	—	—	—	—	—	—	—
Astragalus fetmensis	—	1	1	—	—	—	3	3	—	—	—
Commelina africana	Herb	1	1	—	—	—	—	—	—	—	—
Misopates orontium	—	1	1	—	—	—	2	2	—	—	—
Nephrophyllum abyssinicum	Herb	1	1	—	—	—	—	—	—	—	—
Not identified	—	1	1	—	—	—	—	—	—	—	—
Total		1771	1252	309	131	79	381	262	77	26	16

Species arranged with descending total number of seeds.
[a] Plant nomenclature follows Cufodontis (1953–1972), Hedberg and Edwards (1989, 1995), Friis (1992), Edwards et al. (1995, 1997, 2000).

4. Discussion

Even though the original vegetation status of the study sites at the time of establishment of the enclosures was not documented, the results from the present study clearly demonstrated the importance of enclosures in the restoration of degraded dryland areas. The comparison made between the enclosures and open

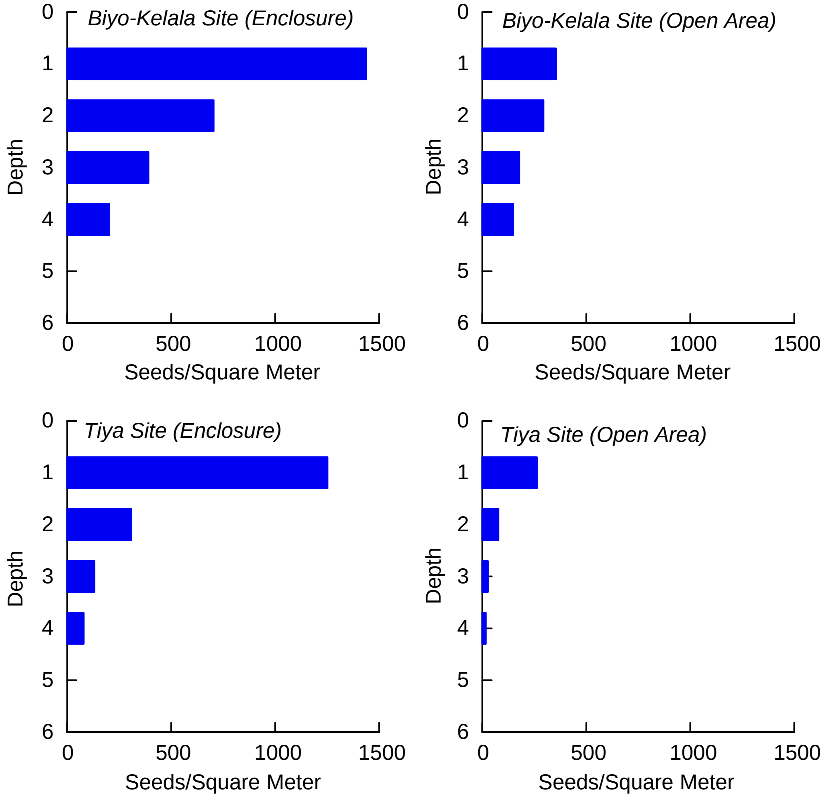

Fig. 4. Depth distribution of seeds in the soil at both sites (soil layers: 1 = 0–3 cm; 2 = 3–6 cm; 3 = 6–9 cm; and 4 = 9–12 cm).

grazing areas of the two study sites showed that the composition, diversity and density of woody species of the above-ground vegetation were higher in the enclosures suggesting rehabilitation of the degraded areas in relatively short periods of time by simply avoiding or minimizing interference of people and domestic animals in the degraded areas, i.e. establishing enclosures (Zerihun and Backéus, 1991). Similar encouraging results have been reported from studies made on enclosures established within the last two decades in Tigray, northeastern Ethiopia (Kindeya, 1997; Emiru, 2002; Kidane, 2002) and southern Welo (Kebrom, 1998). The degraded forestlands in Tigray have been set-aside as enclosures for site rehabilitation, and to date, areas of over 188,432 ha, including areas identified for gum and incense production, are being protected under enclosures (Emiru, 2002).

At Biyo–Kelala site, density of the pioneer species, *Dodonaea angustifolia,* was higher in conformity to findings of a similar study in the degraded drylands of Welo (Tesfaye and Bengtsson, 1999; Tesfaye, 2000), followed by those of *A. saligna*, a planted exotic species, and *Grewia ferruginea*. This may be attributed to the ability of

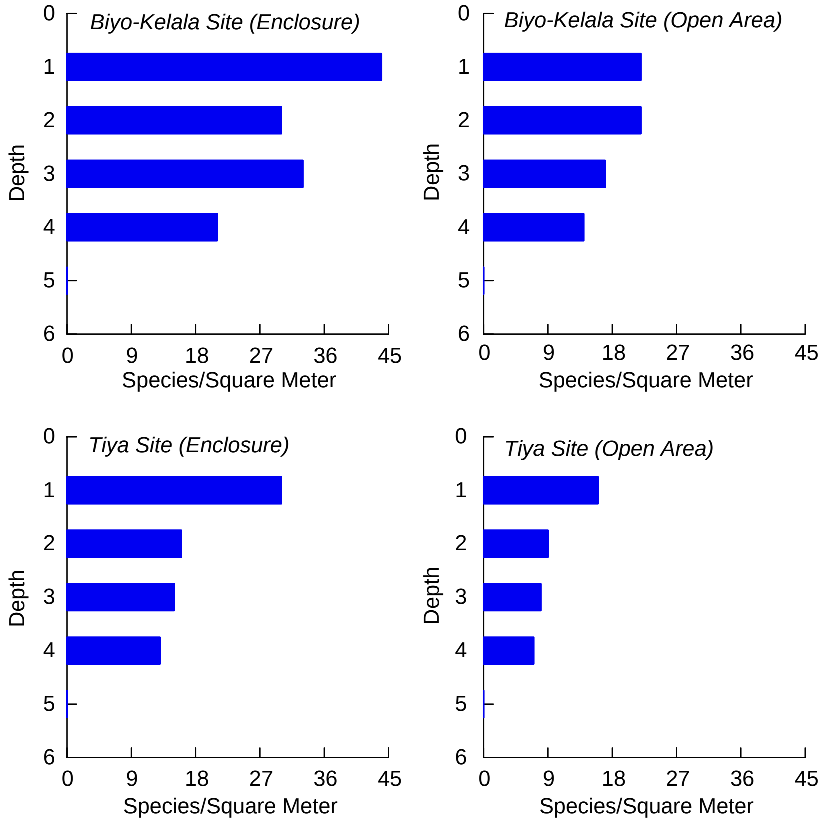

Fig. 5. Depth distribution of species in the soil at both sites (soil layers: 1 = 0–3 cm; 2 = 3–6 cm; 3 = 6–9 cm; and 4 = 9–12 cm).

the species to regenerate via different pathways, namely from recently dispersed seeds (seed rain), long-lived seed reserves in the soil (soil seed bank) (see Tables 3 and 4) and/or sprouting from damaged stumps or roots. At Tiya site, *A. etbaica* was the most dominant species in both the enclosure and open area. Its density was greater in the enclosure than the open area by a factor of two. A similar result was also reported from a study made in Tigray (Emiru, 2002). The continuous disturbance occurring in the open area has prevented the development of vegetation comparable with that of the enclosure in Biyo–Kelala site. Instead, the area has become dominated by *Echinops macrochaetus* and *Sida alba*, which seem to be favored by the disturbance.

Both in the enclosures and open areas at both sites, the lower diameter classes exhibited higher diversity values suggesting that the sites are at an early stage of succession (Silvertown, 1982). Analyses of the population structure, i.e. the number of individuals of some species in each diameter class (Figs. 2 and 3), revealed relatively large number of individuals, seedlings, in the lowest diameter class followed by either a gradual or sharp decline in the next higher diameter classes, more or less forming reversed "J" type of distributions. These trends are indications of normal regeneration status progressing towards stable population structures provided that the sites are protected from further human and animal interferences. Conversely, in Biyo–Kelala site, some species, e.g. *Olea europaea* subsp. *cuspidata* and *Stereospermum kunthianum* possess neither seedlings in the vegetation nor seeds in the soil. They were found in the standing vegetation with densities of about one tree/ha, which may indicate the possibility of local disappearance in the event of death of the existing few individuals. This calls for interventions aimed at facilitating perpetuation of such species, e.g. through enrichment plantation of their seedlings.

At both sites, the overall diversity and diversity in each diameter class revealed higher values for the enclosures than the open areas. The fact that the open grazing land at Biyo–Kelala site exhibited diversity value exclusively for the first diameter class only suggests that saplings and mature individuals are either being continuously cut or seedlings are prevented from developing. The high diversity values of enclosures compared with those of open areas indicate the importance of enclosures for the conservation of genetic resources of the woody species, particularly rare and unique species that are under heavy threat of local extermination and eventual extinction.

The number of species and density of the soil seed banks recorded at both sites was much lower than those reported for dry Afromontane forests in the country (Demel and Granström, 1995; Demel, 1996, 1997b, 1998). This might be attributed to the anthropogenic and natural disturbances that have led to the degradation of the sites over many years, including the associated erosion of the topsoil in which most of the seeds are stored. The nature and degree of disturbances inflicted on a site are major determining factors not only in the number of species and density of soil seed banks but also in the realization of the existing potential of the seed bank (Granström, 1986).

Herbs and grasses had the highest number of species and densities of viable seeds in the soil seed bank while, except the planted *A. saligna,* none of the other woody plants at both sites accumulated significant number of seeds in the soil in concurrence with findings from previous similar works (Demel and Granström, 1995; Demel, 1996, 1997b, 1998; Kebrom and Tesfaye, 2000). Annual herbs and grasses rely on persistent seed banks since their yearly population turn over is at risk of environmental uncertainties, and the seed is the only persistent stage. However, most woody species appear not to rely on persistent seed banks (Parker, 1989) but either on seedling banks or coppicing from damaged stumps (Demel, 1997a). Another explanation for the few seeds of woody plants in the soil seed banks could be the possibility of exhaustion of the available meager soil seed reserves in the degraded areas through germination and recruitment of woody species (Hopkins and Graham, 1984) in the current standing vegetation. The same reason might also explain the disparity in similarity between the soil seed bank and the standing woody vegetation at both sites. Woody species were fewer in the soil seed banks of open areas than enclosures at both sites, suggesting that the effect of disturbance on the soil seed banks is more pronounced in the open areas.

One of the interesting results in the soil seed study was the representation of *A. saligna* with relatively high number of seeds in the Biyo–Kelala enclosure dominated by indigenous woody species. It is becoming more evident that forest plantation of suitable species established in appropriate sites could play an important role in enriching the soil seed banks. The species has, at least, three biological characteristics that place it in a better advantage to accumulate long-live seeds in the soil over other indigenous woody species, namely ability of prolific seeding, possession of hard-seed coated dormant seeds and no or low pressure from indigenous seed predator organisms due to its exotic nature.

Irrespective of the degree of disturbances and species composition, there was a general trend of declining of seed numbers with depth at both sites in agreement with previously reported results (Demel and Granström, 1995; Demel, 1996, 1997b, 1998). The upper 6 cm soil layers constituted the major portion (about 90%) of the soil seed bank, suggesting that if the upper soil layers are affected by disturbance, the contribution of the soil seed bank for future restoration will be minimal. Seed densities at the top 3 cm soil layers were three and half times higher than those in the enclosure compared with those in the open areas at both sites. This clearly indicates the contribution of enclosures in enhancing the accumulation of seeds in the soil as reserves for future sources of regrowth in the event of disturbances.

The establishment of enclosures assists to improve the overall ecological conditions of degraded areas so that they can provide better products and services for the people. The increase in the number and biomass of perennial and annual grass species was significant at both sites, and the local communities benefit from using these species, through the "cut-and-carry" enclosure management system, for feeding their animals, constructing their grass-thatched huts or both. However, management of the natural resources in the enclosures has to keep the balance between growth and harvest to avoid degradation.

Establishment of enclosures is very advantageous over other methods, e.g. hillside terracing and planting, since it is a fast, cheap and lenient method for the rehabilitation of degraded lands (Bendz, 1986). It is a fast method triggering invasion, germination/sprouting, recruitment, establishment and growth of seedlings, modified underground stems or roots of indigenous species of grasses, herbaceous weeds, shrubs and trees that already exist at the spot either being dormant or suppressed by other plants or unfavorable environmental conditions. These propagules invade the area faster and with better coverage than planted seedlings. It is a cheap method since natural processes lead to regeneration of the vegetation without any human interference and financial investment.

Most forest managers tend to rely heavily on artificial regeneration prescriptions, i.e. tree planting, for achieving desired tree stocking levels and wood production. In addition, people usually consider the vegetation in degraded lands as marginal and non-productive. However, results from the present study have demonstrated that establishment of enclosures coupled with mimicking the course of nature, 'natural silviculture', seems a realistic and viable option for successful plant regeneration and accelerated succession on degraded drylands as can be evidenced from the status of woody vegetation and soil seed banks in enclosures at both study sites. Nevertheless, when and where feasible, it might be advantageous to assist natural regeneration in enclosures with enrichment planting of indigenous and exotic species, such as *A. saligna* at Biyo–Kelala site, to foster speedy succession to rehabilitate heavily degraded areas. In particular, this strategy may prove desirable and useful in areas where sources of seeds or propagules required for the regeneration of plants are limiting.

In general, the present study generated empirical evidence, which demonstrated the actual and potential role of enclosures in enhancing the recovery of vegetation on degraded drylands, provided that they are properly protected and sustainably managed. However, success in maintaining these enclosures with the developing vegetation depends on locality-specific and community-based management systems, including provision of benefits to the local communities in the form of both products and services. Since land degradation is multidimensional and complex so should be the design of its solutions. Therefore, for addressing the problem successfully, e.g. by establishing enclosures, collaboration among concerned bodies, namely Government and Non-Governmental Organizations, researchers, extension workers, administrative bodies, local people, etc., is quite indispensable.

Further studies are recommended on: enclosures established in different agro-ecological zones of the country; processes involved in the regeneration of plants, including dispersal ecology, germination, establishment, growth of seedlings, eco-physiology, etc.; status of the physical environment both before and after enclosure establishment; appropriate silvicultural and management options; diversity of the fauna as well as micro-organisms and their functional relationships with the flora; socio-economic factors that determine sustainability of enclosures.

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