Innovations

Soil Seed Bank Studies in the Vegetation of Islamic Sacred Groves and its Ecological Implication for Restoration of Degraded Forests

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Abstract: *Forest patches are rich in biodiversity and sources of seedlings. These patches are common in the Islamic Sacred Groves of East Africa. However, preserving these patches and restoring the degraded forests around the centers are challenging due to population increment, encroachment, soil degradation, etc. Therefore, we aim to study the soil seed bank's diversity and distribution to restore the area's degraded forests. In this study, 63 plots (20m x 20 m) were involved across eight sites. A total of 189 soil samples were collected from three distinctive soil layers at 3cm intervals at five locations per plot. The total count of seedlings and saplings of height <2 meters and DBH <2.5 cm was used to collect information on the regeneration potential of woody plant species. The soil seed bank diversity and similarity across the sites and soil layers were computed using the Shannon Diversity Index and Jaccard's similarity coefficient. The results show that the sites cover 86 plant species belonging to 33 families dominated by the Poaceae, Asteraceae, and Lamiaceae families. Mersa and Beke Meda sites have the highest (123.41) and the lowest (9.31) seedling density, respectively. Natural regeneration in forest patches revealed that 82% of woody plants were represented by seedlings and saplings. Thirteen species (14%) exhibited no regeneration. 27 (30%) species showed high capability for regeneration, whereas 50 (56%) species showed poor regeneration. These research findings give insight into forest management organizations and suggest restoring the degraded forests in the Islamic cultural centers and surroundings.*

Keywords: *Soil Seed Bank; Forest; Patches; Islamic Sacred Groves; restoration*

1. Introduction

Islamic sacred groves (ISGs) in Wollo are pockets of forests that are rich in biodiversity. These areas are found in various parts of the world, including East Africa, India, Southeast Asia, and other regions (Muhando, 2005; Sheridan, 2009). They are considered sacred and are often used for religious services, ceremonies, and cultural practices. Apart from hosting religious services, ISGs serve as a reservoir for biodiversity and distinctive flora. These areas often serve as important refuges for a wide variety of plant and animal species (Wassie et al., 2005; Mequanint et al., 2020). They can be home to rare, endemic, or endangered species. The sacredness of the places offers protection for species and their habitats. Indigenous people who reside in the area are responsible for their protection through culture, tradition, and religious practices.

The status of these forest patches differs from place to place. However, it has been reduced as a consequence of natural and human-caused disturbances (Aynekulu, 2011). Thus, it creates a challenge for the preservation and restoration of the forest patches. In order to overcome, the challenges, the assessment of regeneration potential through the soil seed bank and natural regeneration is indeed crucial. Thus, assessing the composition and abundance of seeds in the soil seed bank, as well as the viability of these seeds, can gain insights into the potential for natural regeneration of plant species in a given area (Shiferaw et al., 2021). As a result, the information is valuable for making informed decisions about conservation and restoration efforts, as well as for predicting the resilience of an ecosystem to disturbances (Bekeleet al., 2022; Vasiliev, 2022).

Similar to studies in different church forests (Wassie and Teketay, 2006), soil seed bank flora was the main source of plant regeneration in the ISGs of Wollo. Mandela et al. (2020) have demonstrated that it confirms the types and forms of past vegetation and existing flora, as well as forecasts the probable emergence of future seedlings. Furthermore, there are also changes in horizontal and vertical distributions, as well as mobility afterward, due to those differences in time and space (Bose et al., 2021).

As a result of a variety of ecological variables, the destiny of plant seeds is influenced by mature seed dispersal, soil persistence, germination, and development into seedlings under optimal conditions (Vieira and Scariot, 2006). Many aspects of successful plant species conservation and diverse ecosystem management depend on an understanding of persistent seed banks (Shiferaw et al., 2018). Studies on soil seed banks provide vital information for conservation efforts that aim to preserve native plant species and maintain biodiversity in the long run for the benefit of future generations (Wambugu et al., 2023). In addition, it helps in predicting and managing the spread of invasive plants as well.

The regeneration of the species that constitute the forest determines the species composition of individual forest patches. A variety of disturbances, including soil moisture, temperature, micro-scale disturbance, and canopy cover, influence the abundance of seedlings in the forest understory (Hubbel et al., 1999; Bose et al., 2021). Seasonal climate variations that impact the growth stages of seedlings, saplings, coppices, and young trees are a threat to forest regeneration (Khumbongmayun et al., 2006). Negamatsu et al. (2002) found that biotic variables, including herbivores, fungi, and interspecies competition, influence seedling dynamics.

Understanding the role of natural regeneration and the soil seed bank can help in developing effective management strategies to support the recovery of ecosystems, promote biodiversity, and enhance ecosystem services. It can also inform decisions about the need for active restoration interventions, such as planting native species or managing invasive species, to support and enhance natural regeneration processes. Therefore, the assessment of regeneration potential through the soil seed bank and natural regeneration is an important component of ecological maintenance and conservation practices. Thus, determining the capacity of the soil seed banks and the regeneration status of the forest patches of the ISGs was the primary objective of the current study. This led to the identification of priorities for future conservation practices.

2. Materials and Methods

2.1 Description of the study sites

The study was conducted in the ISGs found in Southern and Northern Wollo, which extend from 376 to 500 kilometers north of Addis Ababa. Specific sites are primarily found in the towns of Mersa and Dessie, as well as Kalu, Dessie zuriya, and Tehuledere woreda. These ISGs include the Haik Central Mosque (11°18'54.39"N, 39°40'40.75"E), Geta (10°59'43.33"N, 39°46'58.44"E), Bilen (11°5'40.73"N, 39°36'50.59"E), Beke Meda (11°0'30.40"N, 39°48'50.62"E), Mejit (11°5'53.44"N, 39°45'22.79"E), Kurkur (10°58'43.25"N, 39°43'8.05"E), Mersa (11°39'49.58"N, 39°39'53.37"E), and Ardibo (11°11'56.06"N, 39°4537.83E), as indicated in Figure 1.

The main rainy season in the study area was from July to September, with a short rainy season from March to April. Metrological data were collected from four stations of the National Metrological Agency of Ethiopia located in Dessie, Kombolcha, Haik, and Mersa towns. Study sites exhibited a mean annual rainfall of 930–1186 mm and a mean annual temperature range of 16–21 °C.

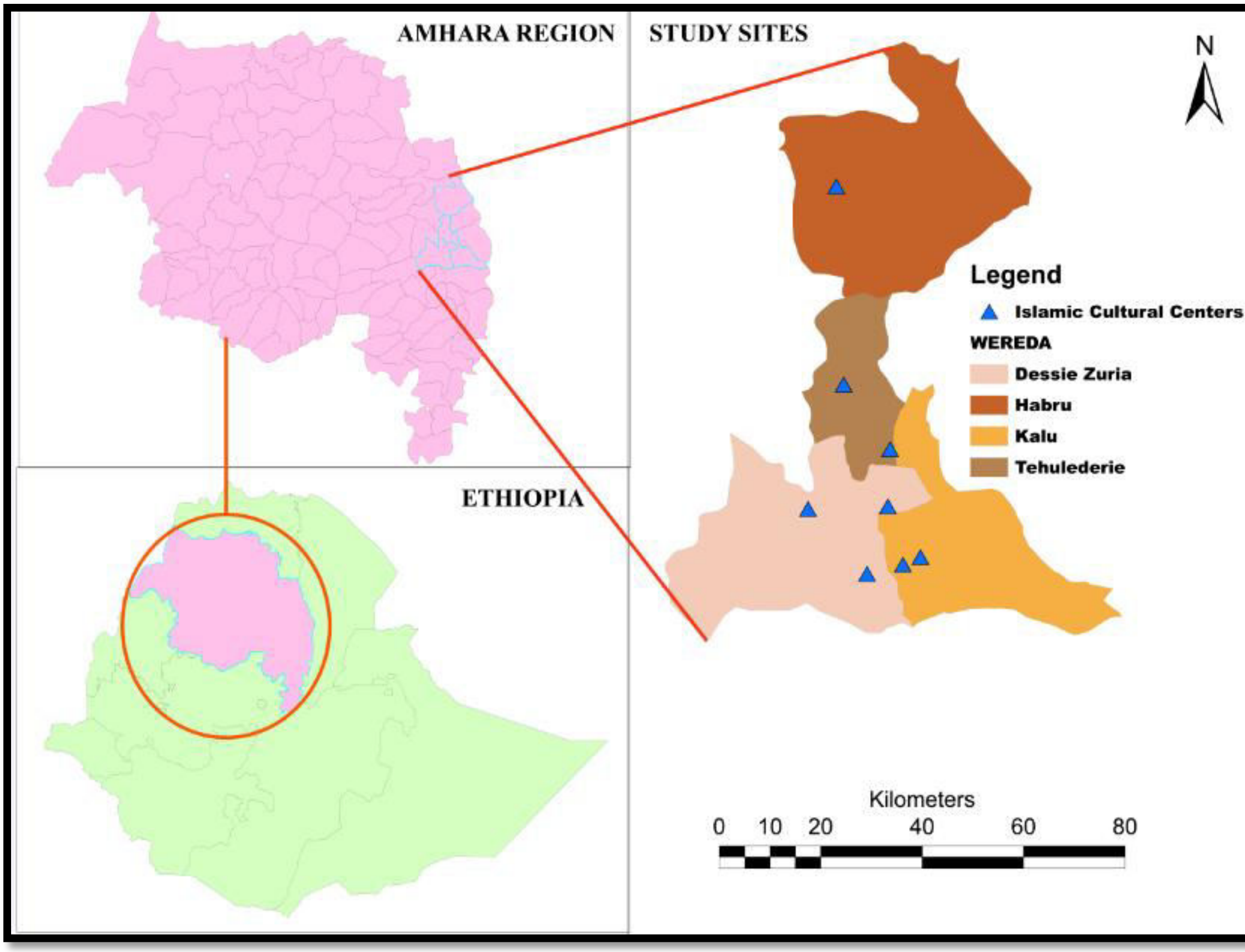

Figure 1. Map of the study areas.

2.2 Sampling Design

The study was carried out to establish the composition, density, and horizontal and vertical distribution of the soil seed banks situated in eight ISGs of Wollo. Five spots measuring 15 cm by 15 cm (225 cm^2) were used to sample the soil. One was placed in the middle of the main sampling plot, and the other four were placed at each of the four corners. Three successive layers of soil from top to bottom measuring 0-3, 3-6, and 6–9 cm thick were carefully extracted from each location using a field knife. They were then placed in separate plastic bags. To reduce variability within the plots, soil samples from identical strata at five locations were combined to create composite samples. The working sample for the study was thereafter selected at random from three equal portions of the composite samples.

The investigations into seedling emergence were carried out in a greenhouse at the Gullele Botanic Garden in Addis Ababa. Six months were spent incubating soil samples for seed germination in the greenhouse on small plastic trays. The bottoms of plastic trays were pierced to allow for appropriate water drainage. After that, samples were misted daily to start the germination process, and successive seedlings were examined every other week. Continuous stirring of soil samples was used to bring seeds that were deeply buried in the soil samples to the surface, encouraging their germination.

Data from mature trees, saplings, and seedlings was used to evaluate the state of woody species regeneration. Senbeta and Teketay (2001) determined that plants with a height of greater than 2 m and DBH >2.5 cm were mature shrubs or trees, while plants with a height of between 1-2 m and DBH 2.5 cm were regarded as saplings, and plants with a length of less than 1 m were taken as seedlings. The sprouting seedlings from the soil seed bank and each specimen from the regeneration study were gathered, pressed, dried, and identified in the National Herbarium (ETH), Addis Ababa University.

2.3 Data Analysis

Species composition, life forms, density of seeds, species richness, and number of individual species (abundance) were recorded in the soil seed bank and above-ground vegetation. Species diversity was calculated using Shannon Wiener diversity (H'). Jaccard's coefficient of similarity was used to test for similarities between the species composition of the soil seed bank at each site. The soil seed bank flora density among sites and soil depth were computed. The regeneration density of woody species was evaluated and categorized in to classes. Species with no regeneration (Class I), species that have a total regeneration density of up to 50 ha^{-1} (Class II), and species with a total regeneration density of more than 50 ha^{-1} (Class III) following Asefa et al., 2014.

3. Results

3.1 Floristic composition of the seed bank

The seed bank study revealed a total of 3002 seedlings belonging to 86 species and 33 families (Table 1). Herbs contribute 86.2% of the life forms, followed by shrubs (5.7%), trees (4.6%), and liana (2.3%) species. Ficus sur, Cordia africana, Croton macrostachyus, Prunus persica, Indigofera hochstetteri, Capparis tomentosa, Lantana camara, Cyathula uncinulata, and Justicia schimperiana were the woody species recovered from the soil seed bank in the ICCs.

Table 1. List of plant species investigated in the soil seed bank.

Botanical Name	Family	Habit
Kalanchoe petitiana A. Rich.	Crassulaceae	Herb
Indigofera hochstetteri Bak.	Fabaceae	Shrub
Salvia tiliifolia Vahl.	Malvaceae	Herb
Panicum hochstetteri Steud.	Poacaeae	Herb
Oxalis corniculata L.	Oxalidaceae	Herb
Dicrocephala integrifolia (L.f.) Kuntze.	Asteraceae	Herb
Digitaria abyssinica (Hochst. Ex A. Rich.) Stapf.	Poaceae	Herb
Veronica abyssinica Fres.	Scrophulariaceae	Herb
Satureja punctata (Benth.) Briq.	Lamiaceae	Herb
Snowdenia polystachya (Fresen.) Pilg.	Poaceae	Herb
Solanum nigrum L.	Solanaceae	Herb
Aira caryophyllea L.	Poaceae	Herb
Lantana camara L.	Verbenaceae	Shrub
Bidens pilosa L.	Asteraceae	Herb
Ageratum conyzoides L.	Asteraceae	Herb
Cyperus rotundus L.	Cyperaceae	Herb
Ocimum gratissimum L.	Lamiaceae	Herb
Laggera crispata (Vahl) Hepper & Wood	Asteraceae	Herb
Parthenium hysterophorus L.	Asteraceae	Herb
Agrocharis melanantha Hochst.	Apiaceae	Herb
Digitaria ternata (A. Rich.) Stapf	Poaceae	Herb
Helichrysum foetidum (L.) Moench.	Asteraceae	Herb
Cheilalthes farinosa (Forssk.) Kaulf	Sinopteridaceae	Herb
Cordia africana Lam.	Boraginaceae	Tree
Echinochloa colona (L.) Link	Poaceae	Herb
Commelina benghalensis L.	Commelinaceae	Herb
Setaria incrassata (Hochst.) Hack.	Poaceae	Herb
Salvia nilotica Jacq.	Lamiaceae	Herb
Helichrysum schimperi (Sch. Bip. ex A. Rich.) Moeser	Asteraceae	Herb
Cynodon dactylon (L.) Pers.	Poacaeae	Herb
Ficus sur Forssk.	Moraceae	Tree
Satureja simensis (Benth.) Briq.	Lamiaceae	Herb
Aristida adoensis Hochst.	Poaceae	Herb
Asplenium aethiopicum (Burmf) Bech.	Aspleniaceae	Herb
Brachiaria mutica (Forssk.) Stapf	Poaceae	Herb
Cynoglossum geometricum Bakl. & Wright	Boraginaceae	Herb

Verbascum sinaiticum Benth.	Scrophulariaceae	Herb
Acalypha fruticosa Forssk.	Euphorbiaceae	Herb
Cyathula uncinulata (Schrad.) Schinz	Amaranthaceae	Shrub
Datura stramonium L.	Solanaceae	Herb
Pennisetum purpureum Schumach.	Poaceae	Herb
Poa annua L.	Poaceae	Herb
Striga hermonthica (Del.) Benth.	Orobanchaceae	Herb
Capparis tomentosa Lam.	Capparaceae	Shrub
Centella asiatica (L.) Urban	Apiaceae	Herb
Croton macrostachyus Del.	Euphorbiaceae	Tree
Oplismenus hirtellus (L.) P. Beauv.	Poaceae	Herb
Anagalis arvensis L.	Primulaceae	Herb
Festuca abyssinica Hochst. Ex A. Rich	Poaceae	Herb
Oxalis latifolia Kunth.	Oxalidaceae	Herb
Conyza stricta Willd.	Asteraceae	Herb
Eragrostis tef (Zucc.) Trotter.	Poaceae	Herb
Helichrysum forsskahlii (J.F. Gmel.) Hilliard & Burtt	Asteraceae	Herb
Plectheranthus sp.	Lamiaceae	Herb
Eleusine floccifolia (Forssk.) Spreng.	Poaceae	Herb
Galium simense Fresen.	Rubiaceae	Herb
Pennisetum sphacelatum (Nees) Th. Dur. And Schinz	Poaceae	Herb
Prunus persica (L.) Batsch.	Rosaceae	Tree
Rubia cordifolia L.	Rubiaceae	Herb
Setaria pumila (Poir.) Roem. & Schult.	Poaceae	Herb
Andropogon abyssinicus Fresen.	Poaceae	Herb
Arisaema schimperianum Schott	Araceae	Herb
Cotula abyssinica Sch.-Bip. ex	Asteraceae	Herb
Echinochloa stagnina (Retz.) P. Beauv.	Poaceae	Herb
Eragrostis tenuifolia (A. Rich.) Steud.	Poaceae	Herb
Galinsoga parviflora Cav.	Asteraceae	Herb
Hypoestes forskaolii (Vahl.) R. Sch.	Acanthaceae	Herb
Kalanchoe lanceolata (Forssk.) Pers.	Crassulaceae	Herb
Sparmannia ricinocarpa (Eckl. & Zeyh.) O. Ktze.	Tiliaceae	Herb
Stephania abyssinica (Dillon & A. Rich) Walp.	Menispermaceae	Climber
Zehneria scabra (Linn. f) Sond.	Cucurbitaceae	Climber
Acalypha volkensii pax	Euphorbiaceae	Herb
Aerva lanata (L.) Juss. ex Schultes	Amaranthaceae	Herb
Argemone mexicana L.	Papaveraceae	Herb

Bidens pilosa L.	Asteraceae	Herb
Cardamine africana L.	Brassicaceae	Herb
Corrigiola capensis Willd.	Brassicaceae	Herb
Geranium arabicum Forssk.	Geraniaceae	Herb
Girardinia bullosa (Steudel) Wedd.	Urticaceae	Herb
Guizotia scabra (Vis.) Chiov.	Asteraceae	Herb
Justicia schimperiana (Hochst. ex Nees) T. Anders.	Acanthaceae	Shrub
Lolium temulentum L.	Poaceae	Herb
Ocimum lamiifolium Hochst. ex Benth.	Lamiaceae	Herb
Oldenlandia monanthos (A. Rich.) Hiern	Rubiaceae	Herb
Paspalum scrobiculatum L.	Poaceae	Herb
Pilea tetraphylla (Steudel) Blume.	Crassulaceae	Herb

The richest families were Poaceae (23 species), which accounted for 26.7% of the total, followed by Asteraceae (15.1%) and Lamiaceae (7%) of the species. The families Acanthaceae, Crassulaceae, and Euphorbiaceae contribute three species (3.5%) each. Eight families (Amaranthaceae, Apiaceae, Boraginaceae, Brassicaceae, Oxalidaceae, Rubiaceae, Scrophulariaceae, and Solanaceae) are represented by two species (2.3%) each. The remaining 19 families are represented by one species each (Figure 2).

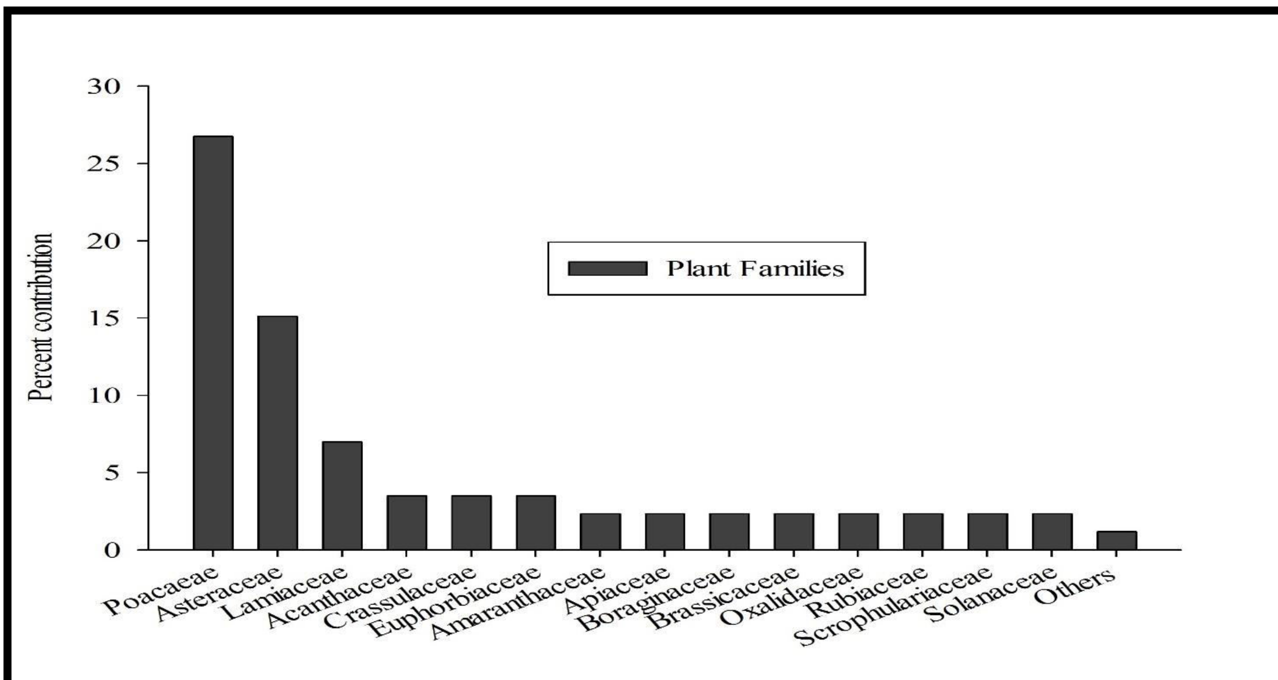

Figure 2. Percent contribution of plant families recovered from the soil seed bank.

Species distribution in different soil strata confirmed that they were not evenly distributed. A higher number of species was exhibited in the top soil layer (0–3 cm) and gradually decreased. At some sites, the middle (3-6 cm) or deep layer (6-9 cm) exhibited more species. From the studied sites, Bilen, Geta, and Mersa had the highest Shannon diversity index and Simpson evenness index, followed by the Beke Meda, Haik, and Kurkur sites. The lowest Shannon diversity index was obtained at the Ardibo and Mejit sites, respectively (Table 2).

Table 2. Species richness and diversity of the soil seed bank flora.

Study sites	Species richness at different soil depth			Shannon Diversity index at different soil depth			Simpson Evenness at different soil depth		
	Upper	Middle	Deep	Upper	Middle	Deep	Upper	Middle	Deep
Ardibo	11	6	7	1.95	1.51	1.34	0.82	0.74	0.66
Beke Meda	17	9	6	2.32	1.66	1.75	0.87	0.74	0.82
Bilen	16	23	24	1.99	2.80	2.89	0.76	0.93	0.93
Geta	26	28	23	2.02	2.47	2.75	0.72	0.83	0.92
Haik	18	22	16	1.68	1.77	2.21	0.66	0.65	0.84
Kurkur	9	8	10	1.58	1.64	1.92	0.73	0.73	0.81
Mejit	11	10	8	1.29	1.86	1.70	0.62	0.79	0.75
Mersa	23	20	20	2.29	1.95	2.13	0.85	0.78	0.81

3.2 Seedling density in the soil seed banks

The total seedling density of species in the seed bank flora was 421seedlings/m^2. The highest seed bank density was recorded in the upper 3 cm layer (211 seedlings/m^2), followed by the middle layer (130 seedlings/m^2), and then gradually decreased with increasing depth to 80 seedlings/m^2 . Ten species with the highest seedling densities were identified, such as Kalanchoe petitiana (151 seedlings/m^2), Indigofera hochstetteri (35 seedlings/m^2), Salvia tiliifolia (34.8 seedlings/m^2), Panicum hochstetteri (22.8 seedlings/m^2), Oxalis corniculata (16 seedlings/m^2), Dicrocephala integrifolia (14 seedlings/m^2), Digitaria abyssinica (11 seedlings/m^2), Veronica abyssinica and Satureja punctata (10 seedlings/m^2), and Snowdenia polystachya (8 seedlings/m^2), respectively (see supplementary 1).

Total seedling density of sites was assessed and found to be higher in Mersa (123 seedlings/m^2), followed by Geta (100 seedlings/m^2), Haik (85 seedlings/m^2), Bilen (34 seedlings/m^2), Kurkur and Mejit (27 seedlings/m^2), Ardibo (18 seedlings/m^2), respectively, and the lowest (9 seedlings/m^2) were found in Beke Meda site (Table 3).

Table 3. The distribution of seedling density along with soil depth

Study sites	Seedling density/m^2 along soil depth			Total Density
	Upper	Middle	Deep	
Ardibo	14.1	1.55	2.54	18.19
Beke Meda	6.91	1.41	0.99	9.31
Bilen	13.96	11.7	8.6	34.27
Geta	56.69	29.9	13.82	100.42
Haik	56.28	20.59	7.62	84.49
Kurkur	17.63	2.68	6.35	26.66
Mejit	19.46	3.81	3.39	26.66
Mersa	75.74	34.84	12.83	123.41
Total Density	260.77	106.48	56.14	421.41

3.3. **The relationship between aboveground vegetation and seed bank**

From the overall study sites, the standing vegetation and the soil seed bank contributed 204 species and 86 species, respectively. About 54 species (26.5%) of the standing vegetation were found in common. Jaccard's similarity coefficient was 0.16, and Sorenson's similarity was 0.27, which revealed little similarity between the soil seed bank and above-ground vegetation. Regarding separate study forest patches, Jaccard's similarity coefficient ranged from 0.02-0.14, and Sorenson's similarity coefficient ranged from 0.04-0.26. In both coefficients, the forest patches in Ardibo showed the lowest similarity and Mersa showed a relatively higher similarity between the soil seed bank and standing vegetation (Table 4). Nine woody species (10.34%) were encountered in the soil seed bank. The woody species recorded in the soil seed bank were 100% represented in the standing vegetation of the forest patches of the ISGs.

Table 4. Similarity between the soil seed bank flora and above ground vegetation.

Study sites	Species in the soil seed bank	Above ground vegetation	Species in Common	Jaccard's similarity coefficient (JCS)	Sorenson's similarity coefficient (Ss)
Ardibo	15	34	1	**0.02**	**0.04**
Beke Meda	18	35	3	0.053	0.1
Bilen	31	85	14	0.107	0.19
Geta	39	111	19	0.112	0.202
Haik	32	72	13	0.111	0.2
Kurkur	21	58	4	0.048	0.09
Mejit	22	57	6	0.07	0.13
Mersa	34	46	13	**0.139**	**0.245**

3.4Natural Regeneration of woody plant species

The result of the study shows that 78 (88%) of the woody species are represented by seedlings and saplings (see Supplementary 2). Only 11 (12%) plant species, including Cordia monioca, Ficus vasta, Casimiroa edulis, Cyphostemma adenocaula, Eucalyptus globulus, Euphorbia pulcherrima, Grevillea robusta, Jasminum abyssinicum, Melia azedarach, and Pinus radiata, did not show seedling and sapling regeneration. Two of these species, Cordia monioca and Ficus vasta, were indigenous to Ethiopia, and the remaining species were exotic. Similarly, 50 species (55.6%) exhibited poor regeneration, and 27 species (30%) revealed good regeneration potential.

The regeneration of seedlings in the study sites ranges from 13 to 29 species, with Shannon diversity ranging from 2.12 to 2.83. The highest regeneration of seedlings was observed at the Geta site (29 plant species) and the lowest at the Beke Meda site (13 plant species). Similarly, the regeneration of saplings ranges from 13 to 30 plant species, with Shannon diversity ranging from 2.13 to 2.78. Bilen and Geta sites show closer seedling and sapling regenerations (Table 5).

Table 5. Species richness and diversity of seedlings and saplings

Study sites	Seedlings			Saplings		
	Species richness	Shannon Diversity index	Simpson diversity Index	Species richness	Shannon Diversity index	Simpson diversity Index
Beke Meda	13	2.21	0.86	13	2.22	0.86
Bilen	28	2.81	0.92	28	2.68	0.91
Geta	29	2.66	0.90	30	2.69	0.90
Haike	25	2.83	0.92	25	2.78	0.92
Ardibo	15	2.18	0.85	15	2.21	0.86
Kurkur	21	2.80	0.93	21	2.66	0.91
Mejit	20	2.46	0.88	20	2.38	0.87
Mersa	14	2.12	0.83	15	2.13	0.83

3.5 Regeneration Density of woody species

The studied forest patches exhibited different regeneration statuses for woody plants. The highest regeneration density was observed in Geta (21,536 individuals/ha), followed by Mersa (3950 individuals/ha), Beke Meda (3813 individuals/ha), Kurkur (3700 individuals/ha), Ardibo (2800 individuals/ha), Haik (1639 individuals/ha), Mejit (1264 individuals/ha), and the lowest in Bilen (1179 individuals/ha). In each site, some plants were not represented by seedlings or saplings. The density of seedlings ranges from 196 ha^{-1} in the Mejit site to 11982 individuals ha^{-1} in the Geta site. The density of saplings ranges from 100 ha^{-1} in the Mejit site to 8589 individuals ha^{-1} in the Geta site, and the density of trees ranges from 381 ha^{-1} in Ardibo to 1100 ha^{-1} in the Beke Meda sites(Figure 3).

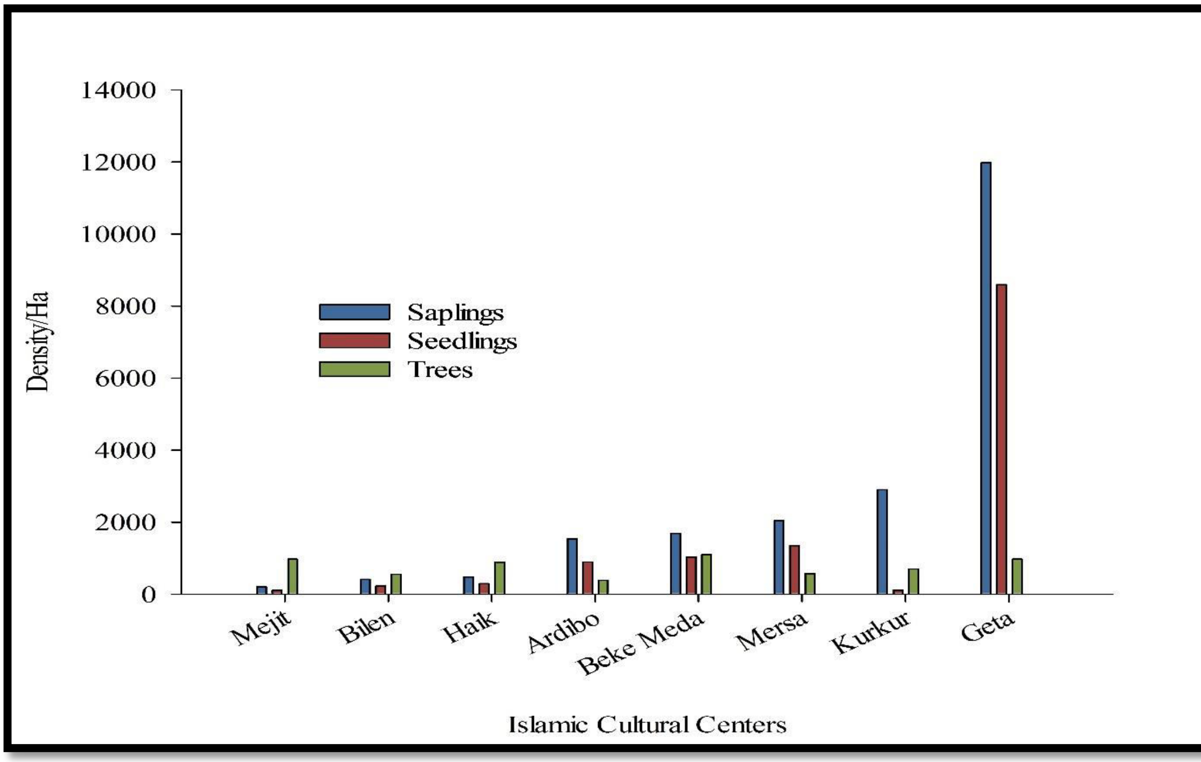

Figure 3. Regeneration density of woody species in ISGs of Wollo.

Based on the analysis of the total regeneration density of the studied woody plants from overall sites, three priority classes were developed (Table 6). Priority Class-I includes species with no regeneration density (i.e., species with no seedlings or saplings). These species include two important tree species (Cordia monioca and Ficus sur)and two endemic species (Echinops longisetus and Echinops kebercho) the remaining tree species in first priority class were exotic species. the second priority class includes species with poor regeneration (i.e., where the total density of regeneration ranges between 1 and 50 individuals per hectare); and third priority class includes species with good regeneration status (i.e., when the total density of regeneration of each woody species exceeds 50 individuals per hectare).

Table 6. Priority list for future conservation of indigenous species.

Priority-I	Priority-II	Priority-III
Cordia monioca*	Ekebergia capensis	Olea europaea subsp. cuspidata
Ficus sur*	Celtis africana	Acacia abyssinica
Cyphostemma adenocaula*	Ehretia cymosa	Euphorbia candelabrum
Echinops kebercho**	Myrica salicifolia	Cordia africana
Echinops longisetus**	Acacia lahai	Juniperus procera
Eucalyptus globulus	Sideroxylon oxyacanthium	Dodonea angustifolia
Casimiroa edulis	Albizia schimperiana	Croton macrostachyus
Euphorbia pulcherrima	Galiniera saxifraga	Grewia ferruginea
Grevillea robusta	Sizygium guineense	Rhus glutinosa subsp. glutinosa
Melia azedarach	Millettia ferruginea	Acacia seyal
Pinus radiata	Olea capensis	Carissa spinarum
	Schefflera abyssinica	Euclea racemosa
	Vernonia amygdalina	
	Acokanthera schimperi	
	Allophylus abyssincus	
	Bersema abyssinica	
	Ficus vasta	
	Psydrax schimperiana	

* Indigenous species with priority of conservation
** Endemic species with priority of conservation

4. Discussion

4.1 Soil Seed Bank

The composition and density of soil seed bank flora reflect the history and disturbance of forest patches (Wassie and Teketay, 2006). It provides basic information for the restoration process (Nilsson et al., 2016). Forest vegetation maintains and increases its populations through the process of regeneration involving soil seed banks (Birhanuet al., 2022). The soil seed bank results proved that there were large quantities of seeds from herbaceous species but a low proportion of woody species (Figure 4). This can be linked to herbaceous plants producing numerous small, persistent seeds, having an improved chance of natural recovery than woody species, and being easily incorporated into the soil to form seed banks (Wassie and Teketay, 2006). On the other hand, the reduced quantity of shrub and tree species in the seed bank was probably due to the short viability of seeds, problems in dormancy, and anthropogenic disturbance (Teketay, 1996; Birhanuet al., 2022).

Figure 4. Germinants from the soil seed bank flora.

In the studied forest patches, seed density was highest in the upper soil layers and gradually decreased with subsequent increases in soil depth. These might be associated with the availability of environmental conditions such as oxygen and light, which are more accessible in the upper soil layer (Tenkir, 2006). In general, seeds from parent plants fall on the soil surface and remain there for some time; later, only a few plant seeds obtain the opportunity to enter the deeper soil layers. For instance, the soil surface cracks permit the seeds to be transported into deeper layers (Asefaet al., 2014). Similarly, if the upper soil layer is degraded by soil erosion or other factors, there may be variation in the soil seed bank down to depth. The variation of seed density with depth might also be explained by differences in seed longevity, seed predation, and mode of seed dispersal (Teketay, 1998).

The relationship between plant species composition in soil seed banks and aboveground vegetation was low. These might be related to anthropogenic disturbances present in the study forest patches. Disturbed habitats have less similarity in species composition between the seed bank and aboveground vegetation. Moreover, seeds of woody plant species that are found in the above-ground flora germinate immediately, or within a few days after dispersal. This result is also in agreement with Wassie and Teketay (2006). Furthermore, the seedling emergence method may decrease the density of the seed bank due to errors associated with seed dormancy and specific environmental requirements for germination (Price et al., 2010).

4.2 Regeneration status of the woody species

The findings of this study show that the total regeneration densities of the studied forest patches differ from each other. This might be associated with canopy cover, human interference, and other disturbances (Teketay, 2005; Khaine et al., 2018; Michere et al., 2022). However, the total regeneration density for the current study was greater than some of the forests in Northern Ethiopia, such as Menfeskidus Monastery Forest (249.24 ha^{-1}) (Negesse and Woldearegay, 2022); Church Forests of Dangila Town (1390 ha^{-1}) (Birhanuet al., 2021); and Bradi Forest (2714 ha^{-1}) (Yemata and Haregewoin, 2022). However, the regeneration status in the current study is lower than the regeneration status reported for the Zijje Maryam Church Forest (15,555.56 ha^{-1}) (Mekonnenet al., 2022) and Menagesha Suba Forest (32,650 ha^{-1}) (Teketay, 1997). This might be associated with the environmental conditions required for regeneration, such as moisture, light, and temperature, which are expected to be more optimal in the described forests, and human encroachment (Khaine et al., 2018; Michere et al., 2022).

The density of seedlings was found to be higher than that of saplings and trees in the Geta, Kurkur, Mersa, Beke Meda, and Ardibo sites, which show the forest patches, are healthy. Whereas in the forest patches of the Mejit, Bilen, and Haik sites, the density of tree species is greater than that of seedlings and saplings, which indicates the forest patches need protection and conservation mechanisms. The result of this study was supported in other studies (Shiferaw et al., 2021; Bekele et al., 2022).
The woody plant species show clear variation in recruitment during the regeneration processes in the study areas. The findings of this study show that the majority woody species had poor regeneration status, some species had good regeneration and few plant species were found without regeneration. Those species without regeneration of seedlings and saplings deserves priority for conservation (Siraj and Zhang, 2018). Most of the tree species that do not have regeneration are exotic species, and two of them are indigenous species (i.e., Cordia monioca and Ficus sur). These two species served as a shade, and people set down under the shade for different social purposes that could damage the seedlings and saplings of the species. In addition, seeds of such species are used as fodder for different organisms, which might cause the loss of healthy seeds for propagation. Two of the endemic shrub species also do not show regeneration in the study sites (i.e. Echinops longisetus, andEchinops kebericho).However, providing a generalized suggestion for deficient seedlings and saplings is difficult since several reasons could account for the lack of and/or poor regeneration status of some woody species. For instance, the hampered regeneration for species could be the result of either most plants not producing seeds due to age or there could have been losses due to predators after reproduction (Mucheye and Yemata, 2020; Gebreselassieet al., 2022).

The study suggests that insufficient regeneration may also result from seedling and sapling grazing, as well as thick litter and herbaceous layers that hinder seed arrival. Furthermore, some species might choose to coppice than conventional ways of regeneration as a means of survival. Related suggestions were noted by Denu (2006), Shibru and Balcha (2004), and Teketay (2005). The present finding of poor regeneration for the majority of woody species indicates that the future fate of this forest could be declining species richness and abundance. Moreover, the complete absence of regeneration shows that the future forest of the study area might lose these species from its floristic list unless proper conservation mechanisms are taken.

5. Conclusions

The diversity, distribution, and quantity of the soil seed bank and seedling regeneration were crucial components of forest dynamics and the recovery of ecosystem functions. The soil seed bank revealed 86 species, which belong to 33 families. Similarly, natural regeneration confirmed 89 plant species. The family

Poaceae was the richest, followed by Asteraceae and Lamiaceae. Herbaceous species revealed the highest seedling density, followed by shrubs, trees, and climbers, respectively. The results confirmed that there was little similarity between above-ground vegetation and the soil seed bank. The forest patches of the studied ISGs were dominated by a few indigenous tree species. Most plant species have poor regeneration status, and few without regeneration of seedlings and saplings. Thus, these research findings give insight and suggest restoring the degraded forests in the ISGs and surrounding areas through establishing nursery sites for the production of priority indigenous tree seedlings.

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Supplementary 1.Seedling density at different soil depth

Name of species	Seedling density at different soil depth			Total
	Upper	Middle	Deep	
Kalanchoe petitiana A. Rich.	79.4	52.3	19.5	151.2
Indigofera hochstetteri Bak.	8.6	11.3	15.1	35.0
Salvia tiliifolia Vahl.	22.1	9.0	3.7	34.8
Panicum hochstetteri Steud.	11.1	7.5	4.2	22.8
Oxalis corniculata L.	6.8	5.2	3.5	15.5
Dicrocephala integrifolia (L.f.) Kuntze.	10.2	3.1	0.6	13.8
Digitaria abyssinica (Hochst. Ex A. Rich.) Stapf.	4.9	3.1	2.5	10.6
Veronica abyssinica Fres.	4.7	2.7	3.1	10.4
Satureja punctata (Benth.) Briq.	5.9	2.1	2.1	10.2
Snowdenia polystachya (Fresen.) Pilg.	5.8	0.8	1.1	7.8
Solanum nigrum L.	2.0	3.7	1.0	6.6
Aira caryophyllea L.	1.7	4.2	0.1	6.1
Lantana camara L.	5.1	0.6	0.4	6.1
Bidens pilosa L.	5.2	0.3	0.3	5.8
Ageratum conyzoides L.	1.8	0.8	3.0	5.6
Cyperus rotundus L.	1.0	1.0	3.4	5.4
Ocimum gratissimum L.	3.5	0.8	0.7	5.1
Laggera crispata (Vahl) Hepper & Wood	1.1	2.0	1.3	4.4
Parthenium hysterophorus L.	2.1	1.3	0.8	4.2
Agrocharis melanantha Hochst.	1.4	1.3	0.7	3.4
Digitaria ternata (A. Rich.) Stapf	2.1	0.6	0.4	3.1
Helichrysum foetidum (L.) Moench.	1.4	0.3	1.4	3.1
Cheilalthes farinosa (Forssk.) Kaulf	1.7	1.3	0.1	3.1
Cordia africana Lam.	1.4	1.0	0.6	3.0
Echinochloa colona (L.) Link	0.8	1.4	0.0	2.3
Commelina benghalensis L.	1.0	0.6	0.4	2.0
Setaria incrassata (Hochst.) Hack.	0.6	0.3	1.0	1.8
Salvia nilotica Jacq.	1.1	0.4	0.1	1.7
Helichrysum schimperi (Sch. Bip. ex A. Rich.) Moeser	0.7	0.6	0.3	1.6
Cynodon dactylon (L.) Pers.	0.6	0.0	0.8	1.4
Ficus sur Forssk.	0.1	0.1	1.1	1.4
Satureja simensis (Benth.) Briq.	1.0	0.4	0.0	1.4
Aristida adoensis Hochst.	1.1	0.1	0.0	1.3

Asplenium aethiopicum (Burmf) Bech.	0.0	0.1	1.0	1.1
Brachiaria mutica (Forssk.) Stapf	0.7	0.3	0.1	1.1
Cynoglossum geometricum Bakl. & Wright	0.0	0.8	0.3	1.1
Verbascum sinaiticum Benth.	1.1	0.0	0.0	1.1
Acalypha fruticosa Forssk.	0.0	1.0	0.0	1.0
Cyathula uncinulata (Schrad.) Schinz	0.7	0.0	0.3	1.0
Datura stramonium L.	0.0	0.7	0.3	1.0
Pennisetum purpureum Schumach.	0.6	0.1	0.3	1.0
Poa annua L.	0.6	0.3	0.1	1.0
Striga hermonthica (Del.) Benth.	0.8	0.0	0.1	1.0
Capparis tomentosa Lam.	0.7	0.1	0.0	0.8
Centella asiatica (L.) Urban	0.6	0.3	0.0	0.8
Croton macrostachyus Del.	0.8	0.0	0.0	0.8
Oplismenus hirtellus (L.) P. Beauv.	0.1	0.6	0.1	0.8
Anagalis arvensis L.	0.0	0.7	0.0	0.7
Festuca abyssinica Hochst. Ex A. Rich	0.7	0.8	0.0	1.6
Oxalis latifolia Kunth.	0.0	0.0	0.7	0.7
Conyza stricta Willd.	0.6	0.0	0.0	0.6
Eragrostis tef (Zucc.) Trotter.	0.7	0.3	0.1	1.1
Helichrysum forsskahlii (J.F. Gmel.) Hilliard & Burtt	0.0	0.1	0.4	0.6
Plectranthus barbatus Andr.	0.3	0.1	0.1	0.6
Eleusine floccifolia (Forssk.) Spreng.	0.0	0.3	0.1	0.4
Galium simense Fresen.	0.0	0.3	0.1	0.4
Pennisetum sphacelatum (Nees) Th. Dur. And Schinz	0.3	0.1	0.0	0.4
Prunus persica (L.) Batsch.	0.4	0.0	0.0	0.4
Rubia cordifolia L.	0.1	0.0	0.3	0.4
Setaria pumila (Poir.) Roem. & Schult.	0.3	0.0	0.6	0.8
Andropogon abyssinicus Fresen.	0.0	0.3	0.0	0.3
Arisaema schimperianum Schott	0.0	0.0	0.3	0.3
Cotula abyssinica Sch.-Bip. ex	0.0	0.1	0.1	0.3
Echinochloa stagnina (Retz.) P. Beauv.	0.0	0.0	0.3	0.3
Eragrostis tenuifolia (A. Rich.) Steud.	0.0	0.3	0.0	0.3
Galinsoga parviflora Cav.	0.1	0.1	0.0	0.3
Hypoestes forskaolii (Vahl.) R. Sch.	0.1	0.0	0.1	0.3
Kalanchoe lanceolata(Forssk.) Pers.	0.3	0.0	0.0	0.3
Sparmannia ricinocarpa (Eckl. & Zeyh.) O. Ktze.	0.4	0.1	0.0	0.6

Stephania abyssinica (Dillon & A. Rich) Walp.	0.3	0.0	0.0	0.3
Zehneria scabra (Linn. f) Sond.	0.3	0.3	0.0	0.6
Acalypha volkensii pax	0.0	0.0	0.1	0.1
Aerva lanata (L.) Juss. ex Schultes	0.0	0.1	0.0	0.1
Argemone mexicana L.	0.0	0.1	0.0	0.1
Bidens pilosa L.	0.1	0.0	0.0	0.1
Cardamine africana L.	0.0	0.1	0.0	0.1
Corrigiola capensis Willd.	0.0	0.0	0.1	0.1
Geranium arabicum Forssk.	0.0	0.1	0.0	0.1
Girardinia bullosa (Steudel) Wedd.	0.0	0.0	0.1	0.1
Guizotia scabra (Vis.) Chiov.	0.1	0.0	0.0	0.1
Justicia schimperiana (Hochst. ex Nees) T. Anders.	0.1	0.1	0.0	0.3
Lolium temulentum L.	0.0	0.0	0.1	0.1
Ocimum lamiifolium Hochst. ex Benth.	0.0	0.0	0.1	0.1
Oldenlandia monanthos (A. Rich.) Hiern	0.1	0.4	0.0	0.6
Paspalum scrobiculatum L.	0.0	0.0	0.1	0.1
Pilea tetraphylla (Steudel) Blume.	0.1	0.0	0.0	0.1
	210.6	**129.8**	**81.4**	**420.73**

Supplementary 2. Total List of regenerating woody plant species.

Location	Name	Family	Habit
Beke Meda	Rhus natalensis Krauss	Anacardiaceae	Shrub
Beke Meda	Ehretia cymosa Thonn.	Boraginaceae	Shrub
Beke Meda	Myrica salicifolia A. Rich.	Myricaceae	Tree
Beke Meda	Psydrax schimperiana (A. Rich.) Bridson	Rubiaceae	Tree
Beke Meda	Grewia similis K. Schum.	Tiliaceae	Shrub
Beke Meda	Acokanthera schimperi (A.DC.) Schweinf.	Apocynaceae	Shrub
Bilen	Sideroxylon oxyacanthium Baill.	Sapotaceae	Tree
Bilen	Sida tenuicarpa Vollesen	Malvaceae	Shrub
Bilen	Cupressus lusitanica Mill.	Cupressaceae	Tree
Bilen	Galiniera saxifraga (Hochst.) Bridson	Rubiaceae	Climber
Bilen	Rhamnus prinoides L'Herit	Rhamnaceae	Shrub
Bilen	Rhamnus staddo A. Rich.	Rhamnaceae	Shrub
Bilen	Sida schimperiana Hochst. ex A. Rich.	Malvaceae	Shrub
Bilen	Ficus sur Forssk.	Moraceae	Tree
Geta	Calpurnia aurea (Ait.) Bellth .	Fabaceae	Shrub
Geta	Carissa spinarum L.	Apocynaceae	Shrub

Geta	Euclea racemosa Murr.subsp. schimperi (A. DC.) White	Ebenaceae	Shrub
Geta	Olea europaea L. subsp. cuspidata (Wall. ex G.Don) Cif.	Oleaceae	Tree
Geta	Justicia schimperiana (Hochst. ex Nees) T. Anders.	Acanthaceae	Shrub
Geta	Maytenus addat (Loes.) Sebsebe	Celastraceae	Shrub
Geta	Rumex nervosus Vahl.	Polygonaceae	Shrub
Geta	Euphorbia candelabrum Kotschy	Euphorbiaceae	Tree
Geta	Dodonea angustifolia L f.	Sapindaceae	Shrub
Geta	Jasminum abyssinicum Hochst. ex DC.	Oleaceae	Climber
Geta	Croton macrostachyus Del.	Euphorbiaceae	Tree
Geta	Vernonia leopoldi (Sch. Bip. ex Walp.) Vatke	Asteraceae	Shrub
Geta	Cordia africana Lam.	Boraginaceae	Tree
Geta	Osyris quadripartita Decn.	Santalaceae	Shrub
Geta	Rumex abyssinicus Jacq.	Polygonaceae	Shrub
Geta	Grewia ferruginea Hochst. ex A. Rich.	Malvaceae	Shrub
Geta	Echinops macrochaetus Fresen.	Asteraceae	Shrub
Geta	Rhus glutinosa A. Rich subsp. glutinosa	Anacardiaceae	Tree
Geta	Entada abyssinica Steud ex A. Rich.	Fabaceae	Shrub
Geta	Senna didymobotrya (Fresen.) Irwin & Barneby	Fabaceae	Shrub
Geta	Opuntla ficus-indica (L.) Miller	Cactaceae	Herb
Geta	Celtis africana Burm. f.	Ulmaceae	Tree
Geta	Leucas stachydiformis (Hochsl. ex Benth.) Briq.	Lamiaceae	Herb
Geta	Aloe debranaChristian.	Aloaceae	Herb
Geta	Grewia trichocarpa Hochst. ex A. Rich.	Tiliaceae	Shrub
Geta	Jasminum stans Pax	Oleaceae	Shrub
Geta	Descopodium penninervum (Hochst)	Solanaceae	Shrub
Geta	Nuxia congesta R.Br. ex Fresen.	Stilbaceae	Shrub
Geta	Acanthus eminens C. B. Clarke	Asteraceae	Shrub
Geta	Dovyalis abyssinica (A. Rich.) Warb.	Celastraceae	Shrub
Geta	Millettia ferruginea (Hochst.) Bak	Fabaceae	Tree
Geta	Ficus vasta Forssk.	Moraceae	Tree
Geta	Euphorbia polyacantha Boiss.	Euphorbiaceae	Shrub
Haike	Euphorbia tirucalli L.	Euphorbiaceae	Tree
Haike	Pavetta abyssinica Fresen.	Rubiaceae	Shrub

Haike	Grewia sp	Tiliaceae	Shrub
Haike	Euphorbia polyacantha Boiss.	Euphorbiaceae	Shrub
Haike	Jacaranda mimosifolia D. Don.	Bignoniaceae	Tree
Haike	Zehneria scabra (Linn. f) Sond.	Cucurbitaceae	Climber
Haike	Schefflera abyssinica (Hochst. ex A. Rich) Harms	Araliaceae	Tree
Haike	Maytenus arbutifolia (A. Rich.) Wilezek.	Celastraceae	Shrub
Ardibo	Juniperus procera Hochst. ex Endl.	Cupressaceae	Tree
Ardibo	Ekebergia capensis Sparrm.	Meliaceae	Tree
Ardibo	Euphorbia ampliphylla Pax.	Euphorbiaceae	Tree
Ardibo	Vernonia amygdalina Del.	Asteraceae	Tree
Kurkur	Myrsine africana L.	Myrsinaceae	Shrub
Kurkur	Lippia adoensis Hochst. ex Walp. var. adoensis	Verbenaceae	Shrub
Kurkur	Rosa abyssinica Lindley	Rosaceae	Shrub
Kurkur	Acacia lahai Steud. & Höchst, ex Benth.	Fabaceae	Tree
Kurkur	Clerodendrum myricoides (Hochst.) Vatke	Lamiaceae	Shrub
Kurkur	Albizia schimperiana Oliv.	Fabaceae	Tree
Kurkur	Rhus retinorrhoea Oliv.	Anacardiaceae	Tree
Kurkur	Allophylus abyssincus (Hochst) Radlk.	Sapindaceae	Tree
Kurkur	Psydrax schimperiana (A. Rich.) Bridson	Rubiaceae	Tree
Mejit	Sizygium guineense (Willd.) DC.subsp. guineense	Myrtaceae	Tree
Mejit	Olea capensis L.	Oleaceae	Tree
Mejit	Phytolacca dodecandra L'Herit.	Phytolaccaceae	Climber
Mejit	Maytenus addat (Loes.) Sebsebe	Celastraceae	Shrub
Mejit	Bersema abyssinica Fresen.	Melianthaceae	Tree
Mersa	Acacia abyssinica Hochst ex. Benth	Fabaceae	Tree
Mersa	Lantana camara L.	Verbenaceae	Shrub
Mersa	Acacia seyal Del.	Fabaceae	Tree
Mersa	Dovyalis caffra (Hook. f. & Harv.) Hook. f.	Flacourtiaceae	Shrub
Mersa	Ficus sur Forssk.	Moraceae	Tree
Mersa	Eucalyptus camaldulensis Dehnh.	Myrtaceae	Tree
Mersa	Capparis tomentosa Lam.	Capparaceae	Tree
Mersa	Ricinus communis L.	Euphorbiaceae	Shrub

Supplementary 3. Regeneration Density of woody plant species.

Study sites	Species Name	Sampled Area (ha)	Seedling Density/ ha	Sapling Density/ ha	Tree Density/ ha	Total Regeneration Density
Ardibo	Acacia abyssinica Hochst. ex Benth .	0.16			62.5	62.5
Ardibo	Calpurnia aurea (Ait.) Bellth .	0.16			62.5	62.5
Ardibo	Carissa spinarum L.	0.16			12.5	12.5
Ardibo	Cordia africana Lam.	0.16			93.8	93.8
Ardibo	Croton macrostachyus Del.	0.16			37.5	37.5
Ardibo	Ekebergia capensis Sparrm.	0.16	481.3	281.3	50.0	812.5
Ardibo	Euphorbia ampliphylla Pax.	0.16	62.5	31.3	6.3	100.0
Ardibo	Euphorbia candelabrum Kotschy	0.16			6.3	6.3
Ardibo	Grewia ferruginea Hochst. ex A. Rich.	0.16			12.5	12.5
Ardibo	Juniperus procera Hochst. ex Endl.	0.16	956.3	531.3	12.5	1500.0
Ardibo	Vernonia amygdalina Del.	0.16	31.3	43.8	25.0	100.0
Beke Meda	Acokanthera schimperi (A.DC.) Schweinf.	0.16	43.8	18.8	6.3	68.8
Beke Meda	Calpurnia aurea (Ait.) Bellth .	0.16			87.5	87.5
Beke Meda	Carissa spinarum L.	0.16			25.0	25.0
Beke Meda	Celtis africana Burm. f.	0.16			31.3	31.3
Beke Meda	Ehretia cymosa Thonn.	0.16	343.8	206.3	50.0	600.0
Beke Meda	Entada abyssinica Steud ex A. Rich.	0.16			81.3	81.3
Beke Meda	Euphorbia candelabrum Kotschy	0.16			118.8	118.8
Beke Meda	Grewia similis K. Schum.	0.16	50.0	37.5	0.0	87.5
Beke Meda	Myrica salicifolia A. Rich.	0.16	306.3	193.8	0.0	500.0
Beke Meda	Olea europaea subsp. cuspidata (Wall. ex G.Don) Cif.	0.16			550.0	550.0
Beke Meda	Osyris quadripartita Decn.	0.16			25.0	25.0

Beke Meda	Psydrax schimperiana (A. Rich.) Bridson	0.16	162.5	112.5	125.0	400.0
Beke Meda	Rhus natalensis Krauss	0.16	775.0	462.5	0.0	1237.5
Bilen	Cupressus lusitanica Mill.	0.36	41.7	27.8	75.0	144.4
Bilen	Entada abyssinica Steud ex A. Rich.				0.7	0.7
Bilen	Euphorbia candelabrum Kotschy				61.1	61.1
Bilen	Ficus sur Forssk.	2.52	0.0	0.0	13.9	13.9
Bilen	Galiniera saxifraga (Hochst.) Bridson	0.36	36.1	27.8	0.0	63.9
Bilen	Juniperus procera Hockst. ex Endl.				288.9	288.9
Bilen	Maytenus addat (Loes.) Sebsebe				8.3	8.3
Bilen	Olea europaea subsp. cuspidata (Wall. ex G.Don) Cif.				75.0	75.0
Bilen	Osyris quadripartita Decn.				5.6	5.6
Bilen	Rhamnus prinoides L'Herit	0.36	50.0	13.9	0.0	63.9
Bilen	Rhamnus staddo A. Rich.	0.36	36.1	27.8	0.0	63.9
Bilen	Rhus glutinosa subsp. glutinosa				19.4	19.4
Bilen	Sida schimperiana Hochst. ex A. Rich.	0.36	27.8	13.9	0.0	41.7
Bilen	Sida tenuicarpa Vollesen	0.36	91.7	61.1	0.0	152.8
Bilen	Sideroxylon oxyacanthium Baill.	0.36	122.2	52.8	0.0	175.0
Geta	Calpurnia aurea (Ait.) Bellth .	0.56	1776.8	962.5	0.0	2739.3
Geta	Carissa spinarum L.	0.56	1405.4	937.5	0.0	2342.9
Geta	Casimiroa edulis La Llave	0.56			3.6	3.6
Geta	Celtis africana Burm. f.	0.56	119.6	71.4	16.1	207.1
Geta	Cordia africana Lam.	0.56	278.6	253.6	12.5	544.6
Geta	Croton macrostachyus Del.	0.56	280.4	344.6	1.8	626.8
Geta	Cupressus lusitanica Mill.	0.56			1.8	1.8
Geta	Descopodium penninervum (Hochst)	0.56	39.3	35.7	0.0	75.0
Geta	Dodonea angustifolia L f.	0.56	492.9	326.8	0.0	819.6
Geta	Dovyalis abyssinica (A. Rich.) Warb.	0.56	21.4	17.9	0.0	39.3
Geta	Echinops macrochaetus Fresen.	0.56	260.7	130.4	0.0	391.1
Geta	Acanthus eminens C. B. Clarke	0.56	26.8	17.9	0.0	44.6
Geta	Entada abyssinica Steud ex A. Rich.	0.56	226.8	117.9	0.0	344.6
Geta	Eucalyptus globulus Labill	0.56			25.0	25.0
Geta	Euclea racemosa Murr.subsp. schimperi (A. DC.) White	0.56	1262.5	1039.3	0.0	2301.8
Geta	Euphorbia candelabrum Kotschy	0.56	512.5	408.9	860.	1782.1

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Geta	Euphorbia polycantha Pax.	0.56	3.6	7.1	0.0	10.7
Geta	Ficus vasta Forssk.	0.56	8.9	3.6	8.9	21.4
Geta	Grewia ferruginea Hochst. ex A. Rich.	0.56	305.4	178.6	0.0	483.9
Geta	Grewia trichocarpa Hochst. ex A. Rich.	0.56	57.1	42.9	0.0	100.0
Geta	Jasminum abyssinicum Hochst. ex DC.	0.56	417.9	212.5	0.0	630.4
Geta	Jasminum stans Pax	0.56	44.6	35.7	0.0	80.4
Geta	Justicia schimperiana (Hochst. ex Nees) T. Anders.	0.56	639.3	605.4	0.0	1244.6
Geta	Maytenus addat (Loes.) Sebsebe	0.56	566.1	444.6	0.0	1010.7
Geta	Millettia ferruginea (Hochst.) Bak	0.56	35.7	0.0	8.9	44.6
Geta	Nuxia congesta R.Br. ex Fresen.	0.56	28.6	44.6	0.0	73.2
Geta	Olea europaea subsp.cuspidata (Wall. ex G.Don) Cif.	0.56	1282.1	1016.1	25.0	2323.2
Geta	Osyris quadripartita Decn.	0.56	298.2	225.0	0.0	523.2
Geta	Rhus glutinosa A. Rich subsp. glutinosa	0.56	216.1	151.8	0.0	367.9
Geta	Rumex abyssinicus Jacq.	0.56	319.6	183.9	0.0	503.6
Geta	Rumex nervosus Vahl.	0.56	508.9	482.1	0.0	991.1
Geta	Senna didymobotrya (Fresen.) Irwin & Barneby	0.56	162.5	128.6	0.0	291.1
Geta	Vernonia leopoldi (Sch. Bip. ex Walp.) Vatke	0.56	383.9	162.5	0.0	546.4
Haik	Acacia seyal Del.	0.36			61.1	61.1
Haik	Celtis africana Burm. f.	0.36			13.9	13.9
Haik	Cordia africana Lam.	0.36			88.9	88.9
Haik	Croton macrostachyus Del.	0.36			22.2	22.2
Haik	Eucalyptus camaldulensis Dehnh.	0.36			100.0	100.0
Haik	Eucalyptus globulus Labill	0.36			41.7	41.7
Haik	Euphorbia candelabrum Kotschy	0.36	55.6	41.7	58.3	155.6
Haik	Euphorbia pulcherima	0.36			22.2	22.2
Haik	Euphorbia tirucalli L.	0.36	180.6	108.3	5.6	294.4
Haik	Grevillea robusta R. Br.	0.36			11.1	11.1
Haik	Grewia ferruginea Hochst. ex A. Rich.	0.36	69.4	44.4	13.9	127.8
Haik	Jacaranda mimosifolia D. Don.	0.36	27.8	13.9	30.6	72.2
Haik	Maytenus arbutifolia (A. Rich.) Wilezek.	0.36	5.6	2.8	0.0	8.3
Haik	Olea europaea subsp. cuspidata (Wall. ex G.Don) Cif.	0.36			375.0	375.0

Haik	Pavetta abyssinica Fresen.	0.36	88.9	47.2	36.1	172.2
Haik	Schefflera abyssinica (Hochst. ex A. Rich) Harms	0.36	19.4	13.9	0.0	33.3
Haik	Zehneria scabra (Linn. f) Sond.	0.36	25.0	13.9	0.0	38.9
Kurkur	Acacia lahai Steud. & Höchst, ex Benth.	0.16	237.5	10.3	81.3	329.1
Kurkur	Albizia schimperiana Oliv.	0.16	112.5	2.0	0.0	114.5
Kurkur	Allophylus abyssincus (Hochst) Radlk.	0.16	43.8	1.2	0.0	44.9
Kurkur	Celtis africana Burm. f.	0.16			175.0	175.0
Kurkur	Clerodendrum myricoides (Hochst.) Vatke	0.16	250.0	8.7	0.0	258.7
Kurkur	Euphorbia candelabrum Kotschy	0.16			37.5	37.5
Kurkur	Ficus vasta Forssk.	0.16			31.3	31.3
Kurkur	Juniperus procera Hockst. ex Endl.	0.16			118.8	118.8
Kurkur	Lippia adoensis Hochst. ex Walp. var. adoensis	0.16	462.5	20.2	0.0	482.7
Kurkur	Myrsine africana L.	0.16	1318.8	52.4	0.0	1371.1
Kurkur	Olea europaea subsp. cuspidata (Wall. ex G.Don) Cif.	0.16			250.0	250.0
Kurkur	Psydrax schimperiana (A. Rich.) Bridson	0.16	25.0	0.8	0.0	25.8
Kurkur	Rhus retinorrhoea Oliv.	0.16	62.5	1.6	0.0	64.1
Kurkur	Rosa abyssinica Lindley	0.16	387.5	9.1	0.0	396.6
Mejit	Acacia abyssinica Hochst ex. Benth	0.28			464.3	464.3
Mejit	Acacia negrii Pic.-Serm.	0.28			117.9	117.9
Mejit	Bersema abyssinica Fresen.	0.28	25.0	10.7	0.0	35.7
Mejit	Capparis tomentosa Lam.	0.28			21.4	21.4
Mejit	Celtis africana Burm. f.	0.28			139.3	139.3
Mejit	Cordia africana Lam.	0.28			82.1	82.1
Mejit	Croton macrostachyus Del.	0.28			14.3	14.3
Mejit	Ehretia cymosa Thonn.	0.28			21.4	21.4
Mejit	Euclea racemosa Murr.subsp. schimperi (A. DC.) White	0.28			7.1	7.1
Mejit	Euphorbia candelabrum Kotschy	0.28			7.1	7.1
Mejit	Grewia ferruginea Hochst. ex A. Rich.	0.28			3.6	3.6

Mejit	Maytenus addat (Loes.) Sebsebe	0.28	25.0	17.9	0.0	42.9
Mejit	Olea capensis L.	0.28	46.4	25.0	0.0	71.4
Mejit	Olea europaea subsp. cuspidata (Wall. ex G.Don) Cif.	0.28			0.0	0.0
Mejit	Phytolacca dodecandra L'Herit.	0.28	42.9	28.6	7.1	78.6
Mejit	Sizygium guineense (Willd.) DC.subsp. guineense	0.28	57.1	17.9	82.1	157.1
Mersa	Acacia abyssinica Hochst ex. Benth	0.48	908.3	602.1	33.3	1543.8
Mersa	Acacia seyal Del.	0.48	195.8	120.8	27.1	343.8
Mersa	Capparis tomentosa Lam.	0.48	66.7	45.8	0.0	112.5
Mersa	Celtis africana Burm.f.	0.48			60.4	60.4
Mersa	Cordia africana Lam.	0.48			68.8	68.8
Mersa	Cordia monoica Roxb.	0.48			25.0	25.0
Mersa	Croton macrostachyus Del.	0.48			10.4	10.4
Mersa	Dovyalis caffra (Hook. f. & Harv.) Hook. f.	0.48	187.5	125.0	0.0	312.5
Mersa	Ehretia cymosa Thonn.	0.48			47.9	47.9
Mersa	Eucalyptus camaldulensis Dehnh.	0.48	85.4	54.2	104.2	243.8
Mersa	Euphorbia tirucalli L.	0.48			85.4	85.4
Mersa	Ficus sur Forssk.	0.48	125.0	75.0	10.4	210.4
Mersa	Ficus vasta Forssk.	0.48			2.1	2.1
Mersa	Lantana camara L.	0.48	447.9	297.9	0.0	745.8
Mersa	Melia azedarach L.	0.48			18.8	18.8
Mersa	Olea europaea subsp. cuspidata (Wall. ex G.Don) Cif.	0.48			72.9	72.9
Mersa	Ricinus communis L.	0.48	20.8	20.8	0.0	41.7
Mersa	Ziziphus spina-christi (L.) Desf.	0.48			4.2	4.2