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Soil Seed Bank and Seedlings Bank Composition and Diversity of Wondo Genet Moist Afromontane Forest South Central Ethiopia

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Abstract: Wondo Genet Afromontane forest is one of the few remnant forests in the country. However, it is experiencing deforestation and fragmentation that limits restoration possibilities. The soil seed were studied to better understand the potential contribution of the soil seed and seedling banks to the natural regeneration and generate information that would assist in selecting appropriate rehabilitation and restoration activities. A total of 75 (20×20 m) quadrats were sampled. Diameter at breast height ≥2 cm and stem height ≥2 m were measured for all woody species encountered and the number of seedlings and saplings were counted. Elevation, slope and aspect were also recorded. At the center of each quadrat, a 10×10 cm plot was marked and three separate soil layers were collected and incubated in a glasshouse for 12 months. Data was analyzed using a combination of analytical methods, such as descriptive statistics, correlation of environmental variables with seedling density using R-Software and ordination techniques using software for Multivariate Analysis of Ecological Data (PC-ORD). A total of 72 woody species from standing vegetation and 60 plant species from incubated soil seed bank were identified. Seedling and sapling density of 1,330 and 917 ha^{-1}, respectively, were recorded. While seedling density was positively correlated with tree density ($r = 0.4248$, $p<0.001$), a negative relationship was observed with elevation ($r = -0.3772$, $p<0.001$). Elevation explained 51.21% and slope 24.4% of the variation in regeneration abundance. Wondo Genet forest exhibits a deficiency of seedling and soil seed bank warranting assisted regeneration and reduction of anthropogenic disturbances to allow natural regeneration.

Key words: Seedling, regeneration, soil seed bank, diversity, Afromontane forest

INTRODUCTION

The Afromontane forests in Ethiopia have experienced severe deforestation, fragmentation, loss of biodiversity and impoverishment of ecosystems (Yirdaw, 2002; Teketay *et al*., 2010). Wondo Genet forest is one of the few remnant moist Afromontane forests in the central highlands of Ethiopia (Friis *et al*., 2010). This forest is severely threatened by heavy anthropogenic disturbance and has declined from 16% of the catchment land base to 2.8% within the past three decades alone (Dessie, 2007). The frequency and severity of the ongoing disturbance influences the species composition, demography and regenerative processes of a forest stand and when this disturbance become extreme, it leads to species disappearance or heavy fragmentation that limits restoration possibilities (Lemenih and Teketay, 2006).

Understanding regeneration mechanisms is an important first-step towards a successful implementation of forest rehabilitation as restoration of degraded tropical forest lands rely much on natural regeneration. Seed rain, soil seed bank, seedling bank and coppices are the major sources of natural regeneration (Tesfaye *et al*., 2010). While most species depend on persistent seedlings (seedling bank strategy), many others utilize soil seed bank regeneration mechanism. To determine the potential for adequate regeneration the existence of persistent soil seed banks or seedling banks must be known (Teketay, 2005). Several authors have studied regeneration and soil seed banks in Afromontane forests of Ethiopia (Teketay, 1997; Tekle and Bekele, 2000; Lemenih and Teketay, 2006). Wondo Genet forest has not been included in the research efforts to date. The objective of this study was to begin this research by quantifying the regeneration

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status and soil seed bank composition of the Wondo Genet forest for possible future restoration efforts.

MATERIALS AND METHODS

Study site: Wondo Genet is situated in the south-eastern central highlands of Ethiopia, 263 km from Addis Ababa, at 7° 5'30''N to 7° 7'40''N latitude and 38° 36'55''E to 38° 39'00''E longitude on the eastern slope of the Rift Valley escarpment (Fig. 1). The altitude ranges from 1800-2500 m. The mean annual rainfall is about 1200 mm and it is bimodal. Rain can be expected from March to April and June to August. November to February is relatively dry. The mean monthly temperature ranges from 19°C in August to 25°C in March, April, May and September. The soils are young and of volcanic origin, characterized by well-drained loam or sandy loam and are shallow at steep convex slopes but deeper at lower altitudes (Eriksson and Stern, 1987). The current land use is predominantly smallholder agriculture with an average landholding size of less than one hectare per household. The Wondo Genet forest is the fragmented remnant of a formerly larger and more coherent forest covering the eastern rift flank. The forest possesses and protects important fauna and flora and provides a variety of important ecosystem services (Dessie, 2007).

Vegetation sampling: Systematic quadrat sampling was conducted in 75 (20×20 m) quadrats along four transects. These are similar sample sizes and shapes used by other researchers in Ethiopian Afromontane forests (Feyera, 2006). The first quadrat was located randomly with subsequent quadrats established at 100 m intervals along transects. Transects were spaced 350 m apart. In each quadrat, all woody species having a DBH (Diameter at Breast Height) ≥2 cm and height ≥2 m were measured. Diameter was determined by caliper. Trees too large for the calipers were measured with a diameter tape. A Suunto clinometer was used to measure tree height. Seedlings (height <0.75 m) and saplings (height = 0.75-2 m) (Alelign *et al*., 2007) of woody species were also counted. Environmental parameters including slope (clinometer), elevation (Garmin GPS-72, cross checked with altimeter), aspect (Silva compass) and coordinates (GPS-72) were recorded for each quadrat (square).

A soil seed bank sample was also collected at the center of each of the 75 quadrats. Here a 10×10 cm (100 cm^2) was located and three successive layers, each 3 cm thick (0-3, 3-6 and 6-9 cm) (Lemenih and Teketay, 2006) was removed, to examine the variations in the depth distribution of seeds. Each 3 cm layer was stored in a perforated plastic tray and covered with a cotton cloth. Roots and pebbles were removed from the soil samples.

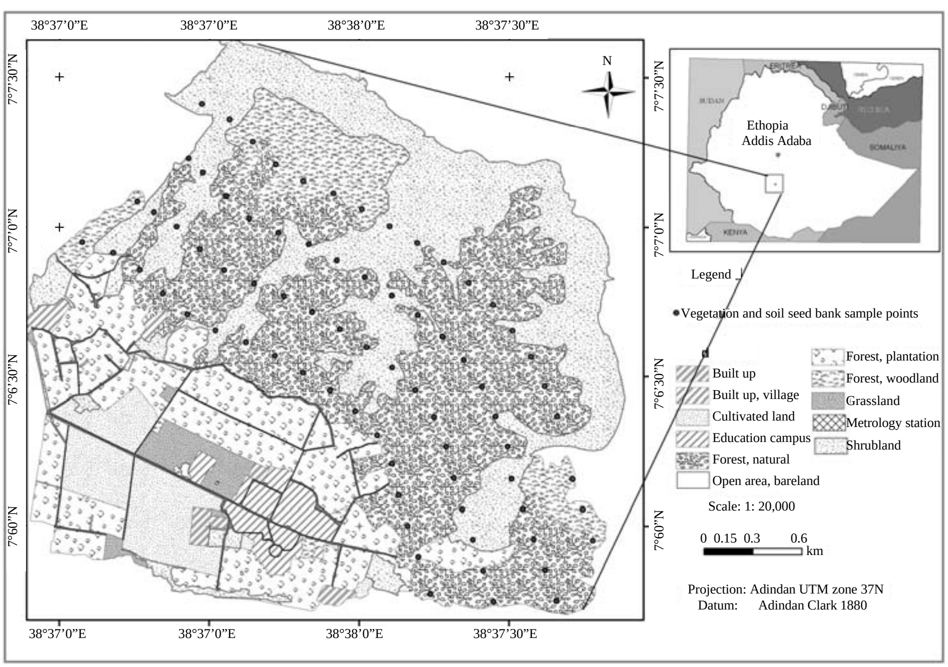

Fig. 1: Location map of study site and sample quadrats

The samples were taken to a greenhouse at Wondo Genet College of Forestry and Natural Resources where they were incubated to stimulate seed germination. The soil samples were spread on cotton cloth to a thickness of two centimeters and kept continuously moist. Emerging and readily identifiable seedlings were counted, recorded and discarded. Plant nomenclature followed published guidelines of the Flora of Ethiopia and Eritrea (Hedberg and Edwards, 1989, 1995; Edwards *et al*., 1997, 2000a, b; Hedberg *et al*., 2003). Plants not readily identifiable were collected, pressed and taken to the Addis Ababa University National Herbarium for identification.

Every month, the soil samples were stirred to stimulate seed germination. This process to encourage seed sprouting was continued for one year.

Data analysis: Density of mature trees, saplings, seedlings and abundance of soil seed bank flora were computed using descriptive statistics, while correlations of structural characteristics and environmental gradients with seedling and sapling density were computed using R-software (Kindt and Coe, 2005). Pearson's critical value was used to determine significance level. Aspect was measured in degrees and converted to a scale of zero to one, following the formula (1-cos (Ø- 45) 2^{-1}, where Ø is aspect in degrees east of true north) (McCune and Grace, 2002). Ordination was completed using Detrended Correspondence Analysis (DCA) by employing PC-ORD for Windows version 4.20 (McCune and Mefford, 2006). Reasons for choosing DCA include its ecological interpretability and its effective spreading out of the points according to sites (Hill and Gauch, 1980). Diversity indices and Jaccard's coefficient of similarity were also computed (Magurran, 2004).

RESULTS

Seedling and sapling composition and density: A total of 72 woody species (≥2 cm DBH) were identified in Wondo Genet's indigenous Afromontane forest belonging to 40 families and 61 genera. The mean tree density and basal area of these woody species was 397.3 and 31.4 m^2 ha^{-1}, respectively. Only 2.8% of the tree species have densities of > 25 stems ha^{-1} and the percentage distribution of trees show 56.2% in the DBH class 2-10 cm indicating that the forest is dominated by medium sized trees. The mean seedling density of the forest was 1,331.3 ha^{-1} (Table 1). Species with the highest seedling density were *Teclea nobilis* (141 or 10.6%) *Calpurnia aurea* (112 or 8.4%), *Acokanthera schimperi* (111 or 8.3%), *Myrsine africana* (80.6 or 6.0%) and *Celtis africana* (80 or 6.0%). A number of species had no seedlings recorded including; *Dracaena afromontana, Cordia africana, Ehretia cymosa* and *Entada abyssinica.*

The mean sapling density was 917 stems ha^{-1}. Species with the highest densities were *Dodonaea angustifolia* with 74 (or 8.10%) saplings, followed by *Myrsine africana* 73.0 (7.96%), *Acokanthera schimperi* 60 (6.54%), *Rhus vulgaris* 58 (6.3%), *Calpurnia aurea* 55 (6%) and *Teclea nobilis* 52 (5.7%). Species with only a single sapling encountered during the survey include; *Allophylus abyssinicus*, *Cordia africana*, *Polyscias fulva*, *Ehretia cymosa*, *Entada abyssinica*, *Oncoba spinosa* and *Steganotaenia araliacea*. A number of species had no saplings recorded including; *Apodytes dimidiata*, *Ficus sur*, *Ficus sycomorus*, *Ficus thonningii* and *Vernonia hochstetteri*. Most of the woody species had few recruits and thus were represented by low seedling and sapling density classes (Fig. 2a-b).

Ordination: Ordination of environmental gradients with regeneration (seedlings and saplings) was conducted (Fig. 3). The proportions of variance (coefficients of determination, R^2 for the correlations between ordination distances and Sorensen's distances) represented by

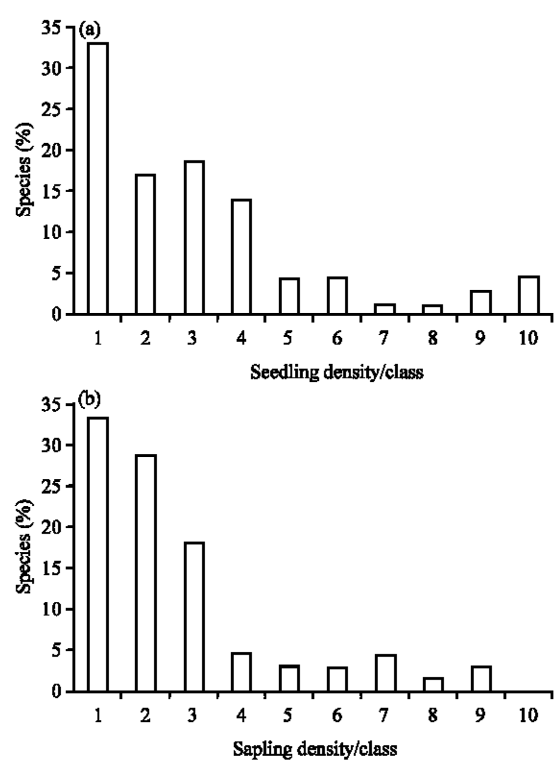

Fig. 2(a-b): (a) Seedlings and (b) Sapling/density class, 1: <5, 2: 5-10, 3: 10-20, 4: 20-30, 5: 30-40, 6: 40-50, 7: 50-60, 8: 60-70, 9: 70-80, 10: >80

Table 1: Densities of mature trees, saplings and seedlings in Wondo Genet natural forest

		Mean tree density		Mean sapling density		Mean seedling density	
S. No.	Species	No.	%	No.	%	No.	%
1	*Abutilon bidentatum*	2.3	0.61	6.3	0.7	1.3	0.10
2	*Acacia abyssinica*	0.7	0.18	0.0	0.0	2.3	0.18
3	*Acanthus eminens*	0.3	0.08	0.3	0.0	0.7	0.05
4	*Acokanthera schimperi*	38.7	10.22	6.0	6.5	11.1	8.34
5	*Afrocarpus falcatus*	11.0	2.90	7.0	0.8	12.0	0.90
6	*Albizia schimperiana*	9.3	2.46	9.0	1.0	18.7	1.40
7	*Allophylus abyssinicus*	1.3	0.34	0.3	0.0	2.7	0.20
8	*Allophylus macrobotrys*	3.7	0.98	6.0	0.7	11.7	0.88
9	*Apodytes dimidiata*	0.3	0.08	0.0	0.0	1.7	0.13
10	*Bersama abyssinica*	4.3	1.14	16.7	1.8	17.3	1.30
11	*Buddleja polystachya*	4.3	1.14	44.7	4.9	21.7	1.63
12	*Calpurnia aurea*	5.0	1.32	55.3	6.0	11.2	8.41
13	*Canthium oligocarpum*	3.7	0.98	5.3	0.6	34.3	2.58
14	*Carissa spinarum*	2.7	0.71	6.3	0.7	6.0	0.45
15	*Cassipourea malosana*	19.0	5.02	22.3	2.4	31.0	2.33
16	*Celtis africana*	43.3	11.43	21.7	2.4	80.3	6.03
17	*Chionanthus mildbraedii*	5.3	1.40	8.3	0.9	3.0	0.23
18	*Clerodendrum myricoides*	0.3	0.08	2.0	0.2	5.3	0.40
19	*Coffea arabica*	1.3	0.34	5.3	0.6	22.3	1.68
20	*Combretum molle*	23.0	6.07	8.7	0.9	22.0	1.65
21	*Cordia africana*	3.7	0.98	0.3	0.0	0.0	0.00
22	*Croton macrostachyus*	11.0	2.90	13.0	1.4	22.7	1.70
23	*Dodonaea angustifolia*	3.0	0.79	74.3	8.1	60.3	4.53
24	*Dracaena afromontana*	1.3	0.34	2.7	0.3	0.0	0.00
25	*Dracaena steudneri*	1.7	0.45	6.3	0.7	2.3	0.18
26	*Ehretia cymosa*	1.3	0.34	0.3	0.0	0.0	0.00
27	*Ekebergia capensis*	1.3	0.34	6.0	0.7	1.3	0.10
28	*Entada abyssinica*	0.3	0.08	0.3	0.0	0.0	0.00
29	*Erica arborea*	2.0	0.53	17.7	1.9	19.0	1.43
30	*Erythrococca trichogyne*	3.3	0.87	12.0	1.3	33.7	2.53
31	*Fagaropsis angolensis*	4.0	1.06	7.3	0.8	7.3	0.55
32	*Ficus sur*	1.3	0.34	0.0	0.0	0.7	0.05
33	*Ficus vasta*	0.3	0.08	0.0	0.0	0.3	0.02
34	*Ficus thonningii*	0.3	0.08	0.0	0.0	0.7	0.05
35	*Flacourtia indica*	2.7	0.71	4.7	0.5	14.7	1.10
36	*Grewia ferruginea*	0.3	0.08	2.3	0.3	5.0	0.38
37	*Hypericum quartinianum*	0.7	0.18	2.7	0.3	11.0	0.83
38	*Hypericum revolutum*	0.3	0.08	12.7	1.4	5.3	0.40
39	*Lepidotrichilia volkensii*	5.0	1.32	5.0	0.5	5.7	0.43
40	*Maesa lanceolata*	1.0	0.26	15.0	1.6	6.0	0.45
41	*Maytenus arbutifolia*	13.3	3.51	37.7	4.1	74.7	5.61
42	*Maytenus undata*	0.3	0.08	1.3	0.1	1.0	0.08
43	*Millettia ferruginea*	21.0	5.54	6.3	0.7	5.0	0.38
44	*Diospyros abyssinica*	2.3	0.61	1.3	0.1	1.7	0.13
45	*Myrsine africana*	0.3	0.08	73.0	8.0	80.7	6.06
46	*Diospyros mespiliformis*	0.7	0.18	13.0	1.4	42.0	3.15
47	*Nuxia congesta*	5.0	1.32	7.0	0.8	8.3	0.63
48	*Olea capensis*	22.0	5.81	5.7	0.6	17.0	1.28
49	*Olea europaea*	0.3	0.08	9.0	1.0	15.0	1.13
50	*Olinia rochetiana*	2.3	0.61	1.0	0.1	3.0	0.23
51	*Oncoba spinosa*	2.0	0.53	0.3	0.0	2.0	0.15
52	*Osyris quadripartita*	3.0	0.79	12.0	1.3	24.7	1.85
53	*Oxyanthus speciosus*	4.0	1.06	1.3	0.1	5.0	0.38
54	*Phoenix reclinata*	0.3	0.08	1.3	0.1	1.0	0.08
55	*Pittosporum viridiflorum*	3.7	0.98	3.3	0.4	9.7	0.73
56	*Polyscias fulva*	4.3	1.14	0.3	0.0	1.0	0.08
57	*Pouteria adolfi-friederici*	8.0	2.11	5.7	0.6	17.3	1.30
58	*Premna schimperi*	1.0	0.26	13.0	1.4	12.7	0.95
59	*Protea gaguedi*	2.0	0.53	43.0	4.7	7.0	0.53
60	*Prunus africana*	0.7	0.18	0.7	0.1	1.0	0.08
61	*Psydrax schimperiana*	3.7	0.98	5.3	0.6	4.3	0.33
62	*Rhus retinorrhoea*	1.7	0.45	22.3	2.4	6.7	0.50
63	*Rhus vulgaris*	1.3	0.34	58.0	6.3	26.0	1.95
64	*Clusia lanceolata*	0.3	0.08	2.3	0.3	0.3	0.02
65	*Steganotaenia araliacea*	0.7	0.18	0.3	0.0	0.7	0.05
66	*Schrebera alata*	2.7	0.71	11.7	1.3	16.7	1.25
67	*Syzygium guineense* subsp. *guineense*	11.0	2.90	11.3	1.2	28.3	2.13
68	*Syzygium guineense* subsp. *macrocarpum*	0.3	0.08	1.3	0.1	0.0	0.00

Table 1: Continue

		Mean tree density		Mean sapling density		Mean seedling density	
S. No.	Species	No.	%	No.	%	No.	%
69	*Teclea nobilis*	14.0	3.70	52.3	5.7	141.3	10.62
70	*Vepris dainellii*	19.0	5.02	11.3	1.2	28.3	2.13
71	*Vernonia auriculifera*	1.3	0.34	36.7	4.0	29.3	2.20
72	*Vernonia hochstetteri*	1.7	0.45	0.0	0.0	6.3	0.48
	Overall	378.8	100.00	917.6	100.0	1331.3	100.00

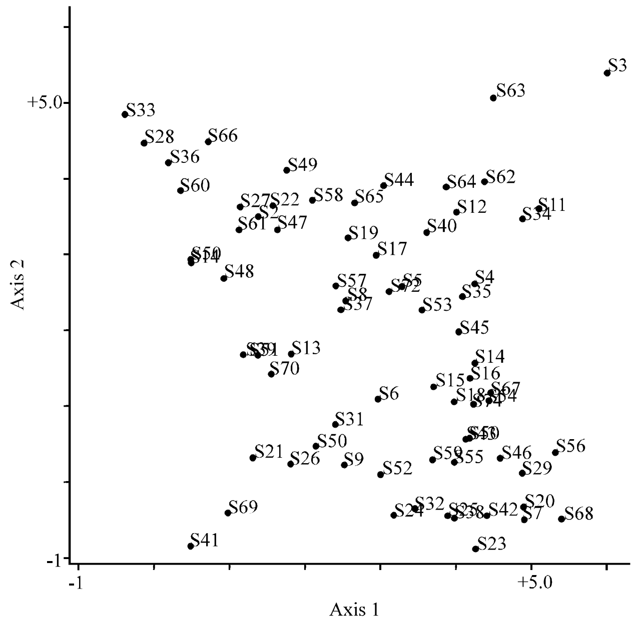

Fig. 3: Detrended correspondence analysis (DCA) ordination of regeneration and environmental gradient. Species numbers are indicated as species serial number in Table 1

axis 1, axis 2 and axis 3 were 0.385, 0.137 and 0.016, respectively (cumulative R^2 = 0.538). Elevation had the strongest significant correlation with Axis 1 (r = 0.566, p<0.01), Axis 3 (r = 0.382, p<0.01) and Axis 2 (r = 0.376, p<0.01). Slope had significant correlation only with Axis 1 (r = 0.341, p<0.01). The correlation of aspect with all the axes was not significant. The maximum length of gradient was 5.65, 5.09 and 2.66 with axis 1, axis 2 and axis 3, respectively. The eigenvalues were 0.74, 0.53 and 0.26 with axis 1, 2 and 3, respectively. Elevation explained 51.21% and slope 24.4% of the variation in regeneration abundance and distribution. The contribution by aspect was not significant.

Correlations: Correlation of seedling and sapling density with forest structural characteristics and environmental gradients was computed. Seedling density was positively and significantly correlated with species abundance (r = 0.4954, p<0.001) and species richness (r = 0.6095, p<0.001) (Fig. 4a, b). Seedling density was positively and significantly correlated with mature tree density (r = 0.4248, p<0.001) (Fig. 4c). Elevation was significantly and negatively correlated with seedling density (r = -0.3772, p<0.001) (Fig. 4d). Sapling density was negatively and significantly correlated with basal area (r = 0.2351, p<0.05) (Fig. 4e). Both slope and aspect was not significantly correlated with seedling density.

Species richness and density of the soil seed bank flora: A total of 60 flowering plant species (grasses, sedges, herbs, lianas, shrubs and trees) were germinated and identified from the Wondo Genet natural forest soil seed bank (Table 2). The identified species belong to 29 families and 51 genera, including, four moncotyledon and 25 dicotyledon families. The specious families were Asteraceae (seven genera, nine species), followed by Poaceae (six genera, seven species), Amaranthaceae (four genera, four species), Fabaceae (four genera, four species), Lamiaceae (three genera, four species) and Cyperaceae (one genera, three species). The ten specious families contributed 66.6% of the total species and 60.7% of the total genera, whereas the 20 species-rich families contributed 85% of the total species and 82% of the total genera. With respect to growth habit, 17 tree/shrub,

Table 2: List of plant species recorded from soil seed bank from Wondo Genet natural forest

Species name	Family	0-3 cm	3-6 cm	6-9 cm	Habit*
Acacia brevispica	Fabaceae	x			L
Acanthus eminens	Acanthaceae	x			S
Achyranthes aspera	Amaranthaceae	x	x	x	H
Acmella caulirhiza	Asteraceae	x	x	x	H
Ageratum conyzoides	Asteraceae	x	x	x	H
Physalis peruviana	Solanaceae			x	S
Dichrocephala integrifolia	Asteraceae	x			H
Amaranthus spinosus	Amaranthaceae	x	x	x	H
Bidens pilosa	Asteraceae	x	x		H
Bidens sp.	Asteraceae	x	x		H
Brucea antidysenterica	Simaroubaceae	x			T/S
Buddleja polystachya	Loganiaceae	x	x	x	T/S
Celosia schweinfurthiana	Amaranthaceae	x	x		H
Celtis africana	Ulmaceae	x		x	T
Chenopodium ambrosioides	Chenopodiaceae	x	x		H
Andropogon distachyos	Poaceae	x	x	x	G
Commelina africana	Commelinaceae	x			H
Commelina latifolia	Commelinaceae			x	H
Satureja punctata	Lamiaceae	x			H
Croton macrostachyus	Euphorbiaceae	x			T
Cyathula cylindrica	Amaranthaceae	x	x		H
Cynodon dactylon	Poaceae	x	x	x	G
Cyperus rotundus	Cyperaceae	x	x	x	G
Cyperus esculentus	Cyperaceae	x	x	x	G
Cyperus rigidifolius	Cyperaceae	x	x	x	G
Digitaria abyssinica	Poaceae	x	x		G
Digitaria velutina	Poaceae	x		x	G
Eleusine indica	Poaceae	x		x	G
Eragrostis schweinfurthii	Poaceae	x	x	x	G
Erica arborea	Ericaceae	x	x		T/S
Erucastrum arabicum	Brassicaceae	x	x	x	H
Ficus sur	Moraceae	x			T
Galinsoga parviflora	Asteraceae	x	x	x	H
Geranium arabicum	Geraniaceae	x			H
Girardinia diversifolia	Urticaceae	x			H
Indigofera spicata	Fabaceae	x	x	x	H
Ipomoea tenuirostris	Convolvulaceae	x	x		H
Kalanchoe densiflora	Crassulaceae	x			H
Kalanchoe lanceolata	Crassulaceae		x		H
Laggera crispata	Asteraceae	x			H
Ledebouria cordifolia	Hyacinthaceae		x	x	H
Leucas martinicensis	Lamiaceae	x	x		H
Leucas sp.	Lamiaceae	x	x		H
Maesa lanceolata	Myrsinaceae	x			T/S
Medicago polymorpha	Fabaceae	x	x	x	H
Ocimum lamiifolium	Lamiaceae	x			H
Oxalis corniculata	Oxalidaceae		x		H
Plantago lanceolata	Plantaginaceae	x	x	x	H
Protea gaguedi	Protaceae	x		x	T/S
Psydrax schimperiana	Rubiaceae	x			T/S
Rubus apetalus	Rubiaceae		x		S
Sida cuneifolia	Malavaceae	x	x		H
Solanum indicum	Solanaceae	x			S
Solanum nigrum	Solanaceae	x	x	x	H
Sporobolus pyramidalis	Poaceae	x			G
Trifolium quartinianum	Fabaceae			x	H
Urtica simensis	Urticaceae	x	x	x	S
Vernonia auriculifera	Asteraceae	x	x	x	S
Vernonia hochstetteri	Asteraceae	x	x	x	S
Zehneria scabra	Cucurbitaceae	x			L

*T: Tree, S: Shrub, H: Herb, L: Liana, T/S: Tree shrub, T/L: Tree Liana, S/L: Shrub Liana, G: Grass, S: Sedges, x: Present

31 herbs, 10 grasses and sedges and two lianas (climbers) were identified from the soil seed bank. Species rank abundance (Fig. 5) showed relative variation in species abundance in the soil seed bank. The most abundant species in the rank abundance was *Cyperus rotundus* (S22), followed by *Laggera crispata* (S38) and *Digitaria abyssinica* (S24).

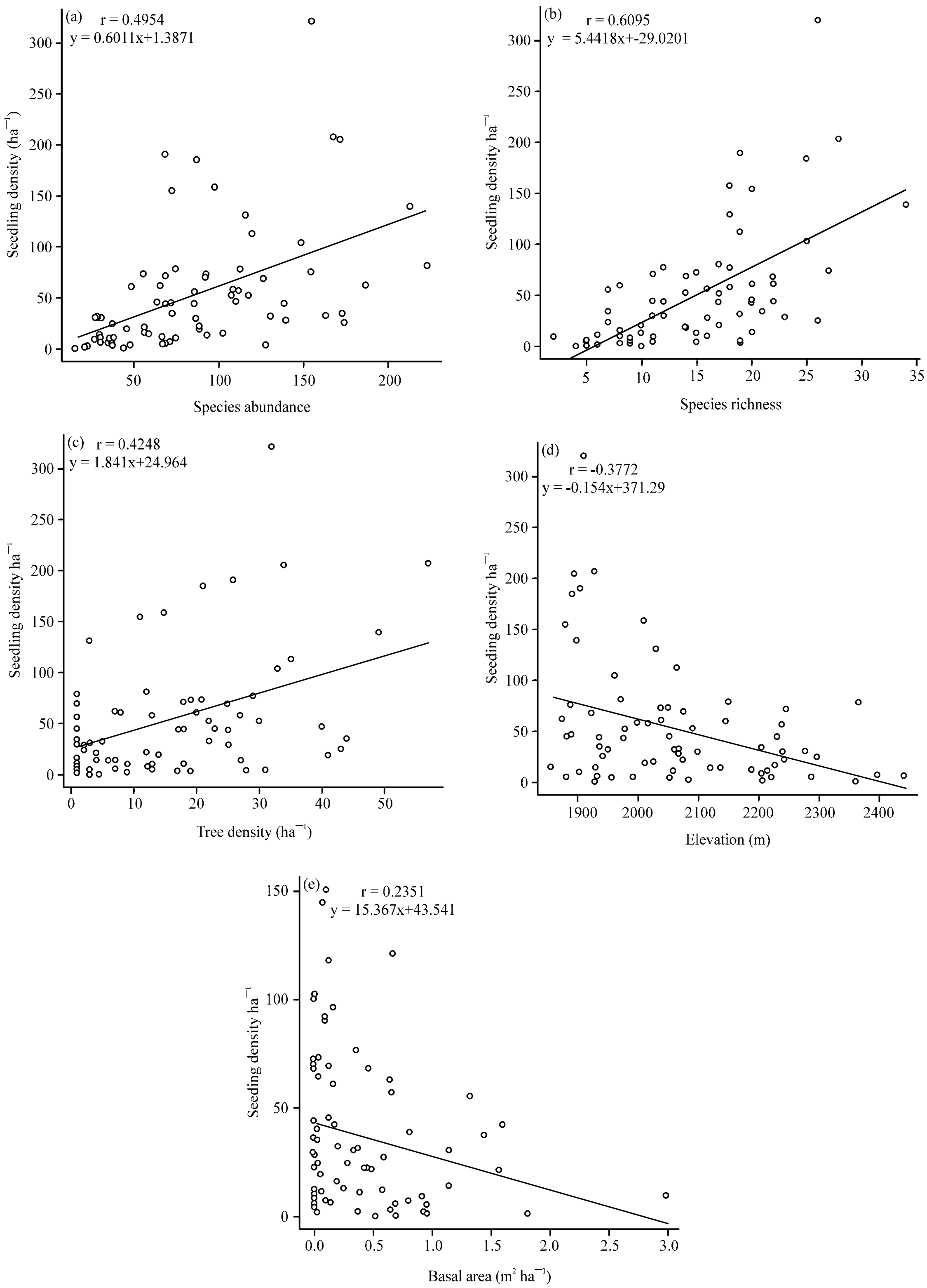

Fig. 4(a-e): Correlation of seedling density with, (a) Species abundance, (b) Species richness, (c) Tree density, (d) Elevation and (e) Sapling density with basal area

Table 3: Diversity and evenness of plant species recovered from soil seed bank

Depth (cm)	Sp. richness	Abundance (m^{-2})	Evenness	J-evenness	Shannon	Simpson	Berger
0-3	54	375	0.513	0.833	3.322	0.939	0.142
3-6	32	180	0.661	0.880	3.051	0.933	0.170
6-9	24	104	0.774	0.919	2.922	0.934	0.154

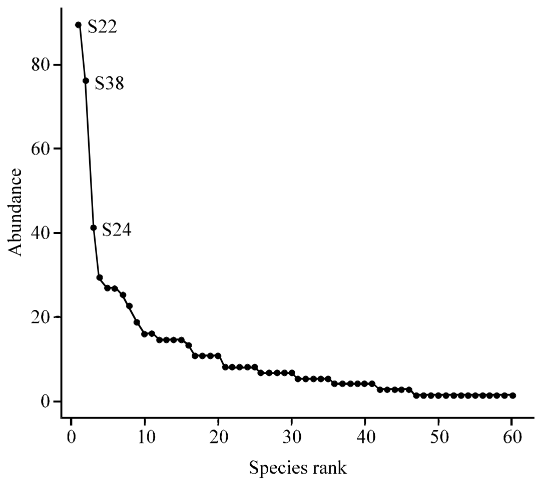

Fig. 5: Rank abundance of species composition from soil seed bank at Wondo Genet forest. Species number given as a serial number in Table 1

A progressive decline in species richness from the seedlings germinated from the soil seed bank was observed across depth layers (Table 3). A were recorded total of 54 species from the upper layer, 32 from the middle and 24 species from the bottom layer. Diversity indices also declined with soil depth. Soil seed bank germinated seedling density also declined progressively following soil depth. The density of germinated seedlings was 375 seedlings/ m^2 in the upper layer, 180 m^{-2} in the middle layer and 104 seedlings/m^2 in the lower layer. Soil seed bank composition varied across quadrats. The higher elevations, with wooded grass land type vegetation, had more density of grasses and sedges (*Cyperus* and *Digitaria* species), whereas the lower elevations, where trees and shrubs are denser, the soil seed bank composition was more of herbaceous and woody species. Comparisons were made for species shared across the depth layers. Out of the 60 species recorded, 19 species were common for the three depth layers e.g., *Buddleja polystachya*, *Amaranthus spinosus*, *Ageratum conyzoides*, *Achyranthes aspera*, *Cyperus rotundus*, *Cyperus esculentus*, *Cyperus rigidifolius*, *Cynodon dactylon*. Others were entirely confined to the upper layer, e.g *Girardinia diversifolia*, *Croton macrostachyus* and *Brucea antidysenterica*. Another set of species, e.g., *Physalis peruviana* and *Commelina latifolia* were confined to the bottom layers.

The Jaccard's coefficient of similarity between seedlings that emerged from soil seed bank and the above-ground vegetation showed 0.16. This low value indicates that very few above-ground vegetative species were represented in the soil seed bank.

DISCUSSION

Forest vegetation maintains and increases its populations through the process of regeneration involving soil seed banks, seedling banks and vegetative sprouts (Grime, 1979; Garwood, 1989; Barnes *et al*., 1998). In this study, several species employ both soil seed and seedlings banks strategies to maintain their population structure. However, the mean sapling and seedling density was lower than other similar montane forests. For instance, Girma and Mosandl (2012) recorded a density of 1,000 saplings and 31,600 seedlings ha^{-1} in Munessa Shashamane forest. This difference is probably due to selective logging of Wondo Genet seed trees, leaving several species with little or no offspring. In the regeneration survey, species with a single sapling include; *Allophylus abyssinicus*, *Cordia africana*, *Polyscias fulva*, Ehretia *cymosa*, *Entada abyssinica*, *Oncoba spinosa* and *Steganotaenia araliacea*. No saplings were recorded for Apodytes *dimidiata*, *Ficus sur*, *Ficus sycomorus*, *Ficus thonningii* and *Vernonia hochstetteri*. Similarly, Tesfaye *et al*. (2010) noted their surprise that not a single *Polyscias fulva* seedling was recorded along the entire altitudinal range in Munessa Shashamane forest. This indicates wide scale removal of tree species populations and genetic resources in Ethiopia's Afromontane forests. This calls for enrichment planting and active restoration measures for several tree species in order to keep them as part of these forests.

Several biotic and abiotic factors affect the establishment, survival and growth of seedlings (Fenner and Kitajima, 2000). Spatial distribution of seedlings is affected by topography through its effect on drainage, moisture and nutrient variation (Enoki *et al*., 1997; Enoki and Abe, 2004). In the ordination of environmental variables, elevation explained 51.21% and slope 24.4% of the variation in regeneration abundance and distribution. Tesfaye *et al*. (2010) also found that elevation was strongly correlated with the seedling abundance in the Shashamane forest. In the present study, elevation was significantly and negatively correlated with seedling density. Biotic factors, such as domestic animal grazing, influence regeneration success. The Wondo Genet forest is continually grazed and this might be one reason for the lower density of seedlings and saplings. Livestock pressure is reported to have negative impact on natural regeneration of indigenous tree species and should be controlled (Wassie *et al*., 2009).

In this study, 60 species were germinated from the soil seed bank. The species mainly represent early successional pioneers. This is comparable with studies in other Ethiopian Afromontane forests. For instance, Teketay, 2005 recorded soil seed flora in the 0-9 cm soil layers ranged between 58 species of flowering plants at Munessa Shashamane (south central Ethiopia) and 92 at Gara Ades (south eastern Ethiopia). At Wondo Genet, the specious families were Asteraceae and Poaceae. The dominance of Asteraceae family was also reported at Gara Ades and Munessa Shashamane montane forests. Gonzalez-Rivas, 2005) mentioned that the seed bank is mainly composed of early successional species that accumulate numerous persistent seeds in the soil, even after the species disappear in the vegetation. Jaccard's Coefficient of Similarity (JCS) in species composition of soil seed bank and standing vegetation yielded a value of 0.16, showing a very low similarity. Lemenih and Teketay (2006) found a JCS value ranging from 0.032 to 0.06 in Munessa Shashamane forest. It was reported that the contribution of woody plants to the total number of seeds in the soil was low. The study stated that the re-growth of Afromontane woody species is totally dependent on the presence of mature forest vegetation and does not depend on the soil seed bank for regeneration after disturbances. Bossuyt and Hermy (2004) reported that, although early successional species disappear from the seed bank (as they also disappear from the standing vegetation), the seed bank gradually assembles from species appearing later in the successional process and/or from isolated remnant trees and recent seed dispersal from nearby vegetation. The occurrence of viable soil seed banks is regarded as an insurance against local extinction of populations during unfavorable periods (Thompson, 1987).

In the present study, spatial variation in density and composition of soil seed bank flora was observed. Mean density of 375, 180 and 104 m^{-2} was recorded in the three successive depth layers. Variation in spatial and horizontal in seed distribution is a function of initial dispersal onto the soil and subsequent movement (Simpson *et al*., 1989). However, due to a long and continuous forest disturbance, the composition and abundance of both the soil seed bank and the seedling bank pool is limited when compared to similar Ethiopian montane forests. For example, a mean density of 912, 278 and 163 m^{-2} of viable seeds in 0-3, 3-6 and 6-9 cm, respectively were recorded in Shashamane forest (Lemenih and Teketay, 2006).

In Wondo Genet, fire incidence might be one of the reasons behind the low density recorded. Santos *et al*. (2010) recorded that the presence of fire corresponds to lower values of germinated seeds when compared to non-fire modalities, irrespective of depth.

Generally, there is a decline in density of soil seed bank flora and a variation in composition along depth layers. The vertical distribution of the soil seed bank and number of species was consistent at Gara Ades, Munessa Shashamane and Menagesha montane forests with the highest densities in the upper three centimeters of soil and then gradually decreasing densities with increasing depth (Teketay, 2005). In this study, density and diversity indices (Shannon and Simpson) declined as depth increased. Variations in species compositions along depths were also observed. Some species e.g., *Girardinia diversifolia*, *Croton macrostachyus*, *Brucea antidysenterica* were entirely confined to the upper layer. Other species, e.g., *Buddleja polystachya*, *Amaranthus spinosus*, *Ageratum conyzoides*, *Achyranthes aspera*, *Cyperus rotundus*, *Cyperus esculentus*, *Cyperus rigidifolius*, *Cynodon dactylon* had distribution in all depth layers. Another set of species, e.g., *Physalis peruviana* and *Commelina latifolia* were confined to the bottom layers. Similar distribution patterns of species were recorded in some Afromontane forests of Ethiopia.

CONCLUSION

Although, some species are well represented in the Wondo Genet seedlings bank and soil seed bank flora, several tree species had little or no soil seed and seedlings banks, indicating very poor reproduction or poor survival. Regeneration deficiencies of such woody species were also reported from other Ethiopian Afromontane forests showing a wide-scale problem. Indications showed that the present situation is due to the numerous anthropogenic disturbances in the montane forests. The rehabilitation of this forest requires immediate reduction of these disturbances to allow natural regeneration to occur along with active restoration tasks. Enrichment plantings and seedling survival activities should also be conducted, monitored and evaluated for effectiveness. Further research studies on the impact of deforestation and fragmentation on reproductive phenology, seed rain, survival and recruitment of seedlings of the tree species exhibiting poor regeneration should be initiated.

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