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Original Research

Soil seed bank Assessment and its implication to natural regeneration in Komto Afromontane moist forest, Oromia Regional State, western Ethiopia

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Abstract

Ethiopia's natural vegetation has been decreasing since the 20th century, necessitating regular monitoring of its conservation status and regeneration capacity. Soil seed bank composition plays a crucial role in restoring damaged land. This study investigated the role of soil seed bank in Komto Forest's natural regeneration. Out of forty sample plots, 27 were used for soil seed bank evaluation, while the remaining 40 were used to gather woody species. Soil samples were taken from four depths, each three centimeters thick. The study analyzed the floral richness, seed density, and depth distribution of persistent seeds in soil seed banks, using Shannon-Wiener Diversity Index and Jaccard's coefficient of similarity. The study found that Asteraceae had the highest percentage of seed banks (21.57%), followed by Solanaceae (9.80%). However, the study found that soil seed banks likely don't play a significant role in the natural regeneration of Komto Forest, as herb is the most common growth form and only five tree species were found in the seed bank investigation. Prior to the irreparable degradation of Komto Forest, proactive restoration methods are crucial, including enrichment planting with native forest tree species.

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INTRODUCTION

Ethiopia is known for its diverse landforms with a wide gradient in elevation. Due to the enormous variation in topography and the associated climatic conditions, the country possesses various vegetation types, ranging from desert scrubs in the northeast to moist Afromontane forests in the southwest (Friis et al., 2010). Previous studies including Friis (1992) and EFAP (1994) confirmed that extensive areas in the Ethiopian highlands were covered by forest. The country is known for its rich plant and animal species and is considered to be the centre of diversity and endemism (Friis et al., 2010; IBC, 2012). Currently, the flora of Ethiopia consists of 5757 species of vascular plants out of which some 10% are considered endemic (Ensermu & Sebsebe, 2014). The vegetation of Ethiopia is also rich in woody plants and is estimated to be about 1000 species.

However, human-induced forest degradation significantly reduced the forest cover and caused the impoverishment of several ecosystems (Friis, 1992; Shibiru, 1995; Million & Leykun, 2001). Komto Forest was no exception to this scenario. A study conducted by Fekadu et al. (2012) and (2013) documented 180 vascular plant species, including economically important trees in Komto Forest. The ongoing disturbance, however, significantly influenced the floristic richness and structure of the forest, which could ultimately lead to the loss of species at the local level or dramatically hamper regeneration capacities. Hence, knowing regeneration strategies, including the composition of persistent seeds in the soil or the presence of dormant seedlings in the understory, is vital to understand the natural regeneration potential of any plant community (Demel, 2005).

Tropical forests vary in their regeneration patterns mainly due to the differences in biotic and abiotic components of the environment where they grow. Thus, forest rehabilitation efforts need an understanding of regeneration mechanisms. Getachew et al. (2010) indicated that forest trees follow numerous regeneration pathways, out of which seed rain and soil seed bank are considered cost-effective and ecologically realisable ones. Some plant propagules may remain in or on the soil of any site after disturbance. These are collectively called soil seed banks. Previous studies on cost-effective regeneration strategies, including Demel (2005), Mulugeta and Demel (2006), Getachew et al. (2010), Haileab et al. (2011), Mamo et al. (2012), all agreed that knowledge of persistent seed composition in the soil and their relationships with aboveground vegetation is vital to select and implement appropriate vegetation restoration strategies.

Komto Forest, one of the remnant patches of natural vegetation in Ethiopia, is under severe anthropogenic pressure. It was known for its rich floristic and structural diversity (Fekadu et al., 2012; 2013). Nowadays, however, the forest is facing severe degradation due to the negligence of the concerned government institutions and the surrounding community. Moreover, people living around Komto Forest are completely dependent on the forest to obtain wood for construction, fuel, and timber. They also use the forest for grazing their livestock. As previous studies on Komto Forest focused only on floristic and structural analysis of aboveground vegetation (Fekadu et al., 2012; 2013) and forest cover change (Milkessa et al., 2020), the status of soil seed banks and their contribution to ecological restoration were not yet studied in the area. As a result, it is not possible to recommend whether area enclosure alone could be sufficient to restore plant communities in Komto moist Afromontane Forest. Thus, this study was conducted to, (1) identify the floristic composition and diversity of the standing vegetation and soil seed banks; (2) determine the vertical distribution of persistent seeds in different soil layers; and (3) examine the role of seed banks in the natural regeneration of Komto Forest.

MATERIALS AND METHODS

Study Area

Komto Forest is found in East Wollega Zone, western Ethiopia 320 km away from Addis Ababa (Figure 1). Geographically, the forest is found at 9°05.10′ to 9°06.35′ N Latitude and 36°36.47′ and 36°38.10′ Longitude E. The elevation range from 2,100 and 2,482 m a.s.l. The forest includes *Cupressus* plantation on its southwestern edge.

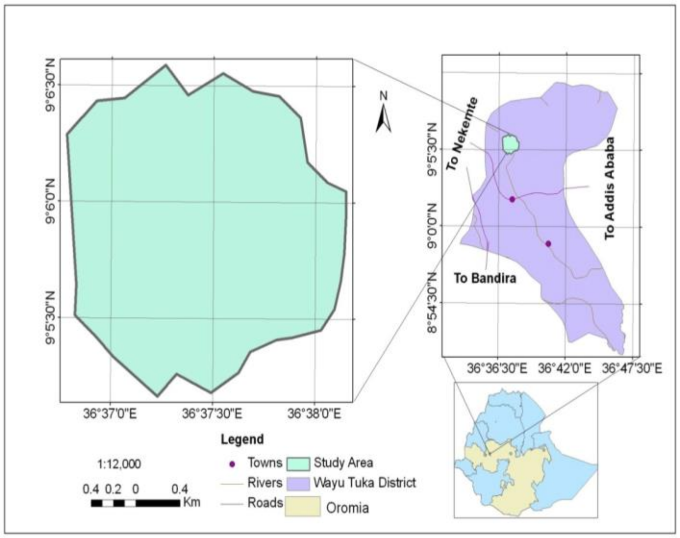

Figure 1. *Study area map (Adopted from Fekadu et al., 2012)*

Data from Nekemte meteorological station indicated a unimodal rainfall with mean annual precipitation 2067 mm and an average temperature of 18.8°C (Figure 2). The area receives maximum rainfall between May and October while January and February are characterized by little or no rainfall. Vegetation type and the characteristic tree species are explained by Fekadu et al. (2013).

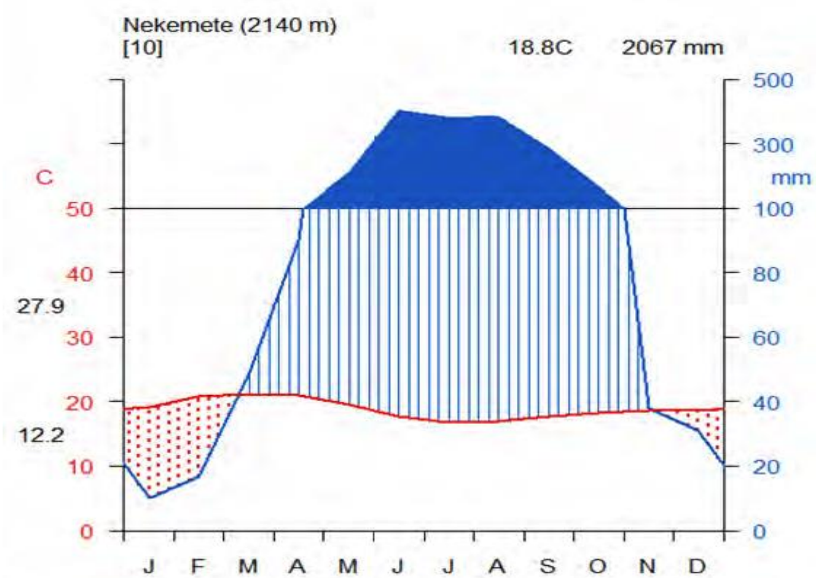

Figure 2. *Climadiagram showing precipitation and temperature of the study area*

Data collection

Aboveground vegetation

A systematic sampling design was utilized after the exploratory survey (Kent and Coker, 1992). At the base of Komto Hill, forty 400 m2 (20 m x 20 m) sample plots were spread up along six 500 m apart line transects, 300 m apart from each other. All woody plants were documented and specimens were gathered in every sampling area. Nomenclature and taxonomic classification were based on the Flora of Ethiopia and Eritrea (FEE).

Soil sample collection

Twenty-seven of the 40 sample plots were selected for soil sample collection. Soil sample collection was made following Feyera and Demel (2001, 2002). Accordingly, soil samples were carefully collected from 5 points each covering 10 cm x 10 cm area in January 2022. According to López-Toledo and Martínez-Ramos (2011), sampling was finished within a week in order to prevent temporal bias. To decrease within-plot variation, a composite soil sample was made by mixing samples from comparable layers in each of the four consecutive 3-centimeter-thick soil layers: 0-3 cm, 3-6 cm, 6-9 cm, and 9-12 cm. In order to ascertain the species composition and vertical distribution of the soil seed bank, 108 soil samples were collected from 27 plots, with each sample taken from four successive strata. Wollega University's greenhouse in Nekemte was the site of the germination test, which involved placing soil samples in plastic bags. In order to make taxonomic identification of species easy, seedling emergence method was used (Christoffoleti and Caetano, 1998).

Greenhouse germination

Before starting the germination experiment, each soil sample was mixed well and all twigs, roots, and rhizome fragments removed. Soil samples from the different soil layers were spread on labelled plastic trays that were perforated to prevent water logging (Figure 3) in a greenhouse at Wollega University main campus. To ensure that shade-tolerant species did not get too much direct sunlight, sample trays were positioned beneath the Table. We watered the soil samples on a regular basis to start the germination process, and we checked on the emergence of the seedlings every other day. Two weeks subsequent to the commencement of the experiment, seedlings began to sprout. In accordance with the Flora of Eritrea and Ethiopia, taxonomic designations and names were applied. Emerging seedlings were removed to avoid competition that may suppress the germination of other seeds once they are identified and counted. Germination in most trays stopped after 3 months, but the soil samples were stirred to expose seeds that did not germinate because they existed in the lower sections of the germination trays, and the germination experiment ran until the end of the 4th month.

Figure 3. *Partial view of seed germination trial in the greenhouse (April, 2022; Photo by Researchers).*

Statistical analysis

Diversity, species richness (S), and evenness (E) were computed for both the standing vegetation and that of soil seed bank flora using Shannon-Weiner diversity and Evenness indices (H') as follows (Magurran, 1988).

$$\mathbf{H'} = -\sum_{i=1}^{s} p_i * \ln p_i \qquad \mathbf{E} = \frac{H'}{\ln S}$$

Where, ***H´*** *= Diversity Index;* ***E*** *= evenness;* P_i *= is the proportion of each species in the sample;* ***S****= total number of species in the sample;* $\ln P_i$ *= natural logarithm of this proportion*.

Floristic similarity between the different soil layers and the standing vegetation was determined by Jaccard's coefficient of similarity (S_j) (Krebs, 1989) as follows.

$$S_j = \frac{a}{a+b+c}$$

Where S_j = *Jaccard similarity coefficient;* ***a****= number of species common to both soil layers;* ***b****= number of species in soil layer 1;* ***c****= number of species in soil layer 2*.

Soil seed density was expressed per square meter. Statistical tests of the variables in different soil layers were compared using analysis of variance (ANOVA). R-statistical software package was used to do all the statistical analyses.

RESULTS AND DISCUSSION

Results

Aboveground vegetation

74 species of woody plants, representing 64 genera and 39 families, make up the above-ground vegetation of Komto Forest (Table 1). The two most numerous plant families are the Asteraceae and the Euphorbiaceae, with six species each. Fabaceae, with four species, and Rubiaceae, with five, were also prominent families.

Table 1

List of woody plant species recorded from aboveground vegetation of Komto Forest (L, Liana; Sh, Shrub; T, Trees)

S/N	Scientific Names	Family	Vernacular Name	Habit
1	*Acanthus eminens* C. B. Clarke	Acanthaceae	Kosorruu	Sh
2	*Achyrospermum schimperi* (Hochst.ex Briq.) Perkins	Lamiaceae	Ajaayee	Sh
3	*Albizia gummifera* (J.F.Gmel.) C.A.Sim.	Fabaceae	Mukaarbaa	T
4	*Allophylus abyssinicus* (Hochst.) Radlkofer	Sapindaceae	Malqaqqoo	T
5	*Apodytes dimidiata* E. Mey. ex Arn.	Icacinaceae	Wandabiyoo	T
6	*Asparagus africanus* Lam.	Asparagaceae	Sariitii	L
7	*Bersama abyssinica* Fresen.	Melianthaceae	Lolshiisaa	T
8	*Brucea antidysenterica* J.F.Mill.	Simaroubaceae	Qomonyoo	Sh
9	*Calpurnia aurea* (Ait.) Benth.	Fabaceae	Ceekaa	Sh
10	*Canthium oligocarpum* Hiern	Rubiaceae	Mixoo qeerramsaa	T
11	*Cassipourea malosana (Baker) Alston*	Rhizophoraceae	Xiilloo	T
12	*Celtis africana* Burm. f.	Ulmaceae	Cayii	T
13	*Clausena anisata* (Willd.) Benth.	Rutaceae	Ulumaayii	Sh
14	*Clematis hirsuta* Perr. & Guill.	Ranunculaceae	Hidda Feetii	L
15	*Clematis longicauda* Steud. ex A. Rich.	Ranunculaceae	Hidda Feetii	L
16	*Clematis simensis* Fresen.	Ranunculaceae	Feetii	L
17	*Clerodendrum cephalanthum* Oliv.	Lamiaceae	Siinxoo Booyyee	Sh
18	*Combretum paniculatum* Vent.	Combretaceae	Hidda Baggii	L
19	*Crotalaria rosenii* (Pax) Milne-Redh ex Polhill	Fabaceae	Baaqelaa Jaldeessaa	Sh
20	*Croton macrostachyus* Del.	Euphorbiaceae	Bakkanniisa	T
21	*Cupressus lusitanica* Mill.	Cuppressaceae	Gaattiraa Faranjii	T
22	*Cyathula uncinulata* (Schrad.) Schinz	Amaranthaceae	Kobboo	Sh
23	*Cyphostemma adenocaule* (Steud .ex A.Rich.) Descoings ex Wild & Drummond	Vitaceae	Hidda Reeffaa	L
24	*Dalbergia lactea* Vatke	Fabaceae	Warrabillee	Sh
25	*Dombeya torrida* (J. F. Gmel.) P. Bamps	Sterculiaceae	Daannisa	T
26	*Dracaena afromontana* Mildbr.	Dracaenaceae	WarqeeQamalee	T
27	*Dracaena steudneri* Engl.	Dracaenaceae	WarqeeQamalee	T
28	*Dregea schimperi* (Decne.) Bullock	Asclepiadaceae	Hidda goorri'saa	L
29	*Embelia schimperi* Vatke	Myrsinaceae	Haanquu	L
30	*Erythrococca trichogyne* (Muel.Arg.) Prain	Euphorbiaceae	Caakkoo	S
31	*Eucalyptus camaldulensis* Dehnh.	Myrtaceae	Baargamoo Diimaa	T
32	*Euphorbia ampliphylla* Pax	Euphorbiaceae	Adaamii	T
33	*Ficus sur* Forssk.	Moraceae	Harbuu	T
34	*Flacourtia indica* (Burm.f) Merr.	Flacourtiaceae	Akuukkuu	Sh
35	*Galiniera saxifrag* (Hochst.) Bridson	Rubiaceae		Sh
36	*Hagenia abyssinica* (Bruce) J.F.Gmel.	Rosaceae	Heexoo	T

S/N	Scientific Names	Family	Vernacular Name	Habit
	Table 1 continues			
37	*Hibiscus macranthus* Hochest.exA.Rich	Malvaceae	Hincinnii Qarancaa	Sh
38	*Jasminum abyssinicum* Hochst. ex DC.	Oleaceae	Hidda Ichilbee	L
39	*Justicia schimperiana* (Hochst. ex Nees) T. Anders.	Acanthaceae	Dhummuugaa	Sh
40	*Lagenaria abyssinica* (Hook.f.) C. Jeffrey	Cucurbitaceae	Buqqee Seexanaa	L
41	*Macaranga capensis* (Baill.) Sim.	Euphorbiaceae	Doggomaa	T
42	*Maesa lanceolata* Forssk.	Myrsinaceae	Abbayyii	T
43	*Maytenus arbutifolia* (A. Rich.) Wilczek	Celastraceae	Hacaacii	Sh
44	*Maytenus undata* (Thunb.) Blakelock	Celastraceae	Ilikkee	T
45	*Pavetta abyssinica* Fresen.	Rubiaceae	Mannisa	Sh
46	*Periploca linearifolia* Quart-Dill. &A.Rich.	Asclepiadaceae	Hiddaaannolee	L
47	*Phragmanthera regularis* (Sprague) M. Gilbert	Loranthaceae	Eertoo	Sh
48	*Phytolacca dodecandra* L'Herit	Phytolaccaceae	Handoodee	L
49	*Pouteria adolfi-friederici* (Engl.) Baehni	Sapotaceae	Sooqee	T
50	*Prunus africana* (Hook.f.) Kalkm	Rosaceae	Hoomii	T
51	*Pycnostachys meyeri* Gurke	Lamiaceae	Mata bokkee	Sh
52	*Ricinus communis* L.	Euphorbiaceae	Qobboo	Sh
53	*Rothmannia urcelliformis* (Hiern) Robyns	Rubiaceae	Buruurii	T
54	*Rubus apetalus* Poir.	Rosaceae	Goraa	Sh
55	*Rumex abyssinicus* Jacq.	Polygonaceae	Dhangaggoo	Sh
56	*Rytigynia neglecta* (Hiern) Robyns	Rubiaceae	Mixoo	Sh
57	*Sapium ellipticum* (Krauss) Pax	Euphorbiaceae	Huddufardaa	T
58	*Solanecio gigas (Vatke) C.Jeffrey*	Asteraceae	JilmaJaldeessaa	Sh
59	*Solanecio mannii* (Hook. f) C. Jeffrey,	Asteraceae		Sh
60	*Solanum anguivi* Lam.	Solanaceae	Hiddii Saree	Sh
61	*Solanum incanum* L.	Solanaceae	HiddiiLoonii	Sh
62	*Solanum marginatum* L.f.	Solanaceae	Hiddiihongorcaa	Sh
63	*Stephania abyssinica* (Dillon & A. Rich) Walp.	Menispermaceae	HidaKalalaa	L
64	*Syzygium guineense* ssp. *afromontanum* F.White	Myrtaceae	Baddeessaa	T
65	*Teclea nobilis* Del.	Rutaceae	Hadheessa	T
66	*Tinospora caffra* (Miers) Troupin	Menispermaceae		L
67	*Trema orientalis* (L.) Bl.	Ulmaceae	Fooffoo	T
68	*Trichilia dregeana* Sond.	Meliaceae	Dhama'ee	T
69	*Urera hypselodendron* (A. Rich.) Wedd.	Urticaceae	HiddaLaanqisaa	L
70	*Vepris dainellii (Pic-Serm.) Kokwaro*	Rutaceae	Hadheessa	T
71	*Vernonia amygdalina* Del.	Asteraceae	Eebicha	T
72	*Vernonia auriculifera* Hiern	Asteraceae	Reejjii	Sh
73	*Vernonia hochstetteri* Sch. Bip. ex Walp.	Asteraceae	Sooyyoma Kormaa	Sh
74	*Vernonia leopoldi* (Sch.Bip.exWalp)Vatke	Asteraceae	Sooyyoma	Sh

Trees and shrubs with 29 and 30 species, respectively are the dominant growth forms while lianas are fewer with only 15 species in the aboveground vegetation (Figure 4).

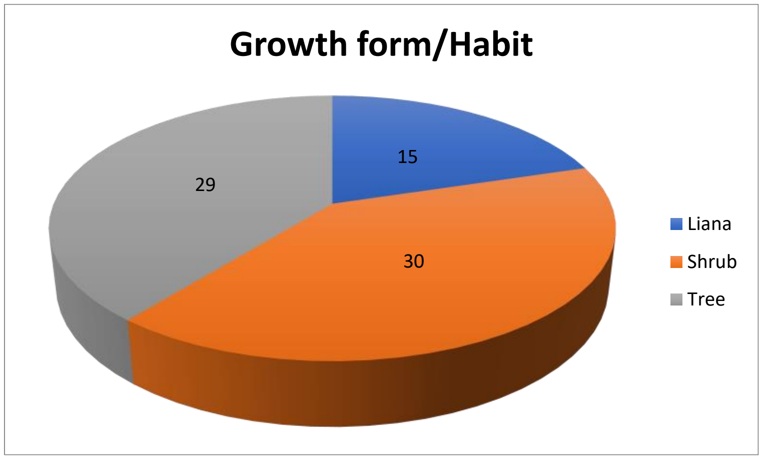

Figure 4. Growth forms of aboveground vegetation

Although natural vegetation has higher mean species diversity and floristic richness than plantation forest, it is not statistically significant in the current study area (Figure 5) (species diversity $F_{1,25}=0.549$, $p=0.47$; richness 0.118, $p=0.74$ and evenness index $F_{1,25}=2.2$, $p=0.15$).

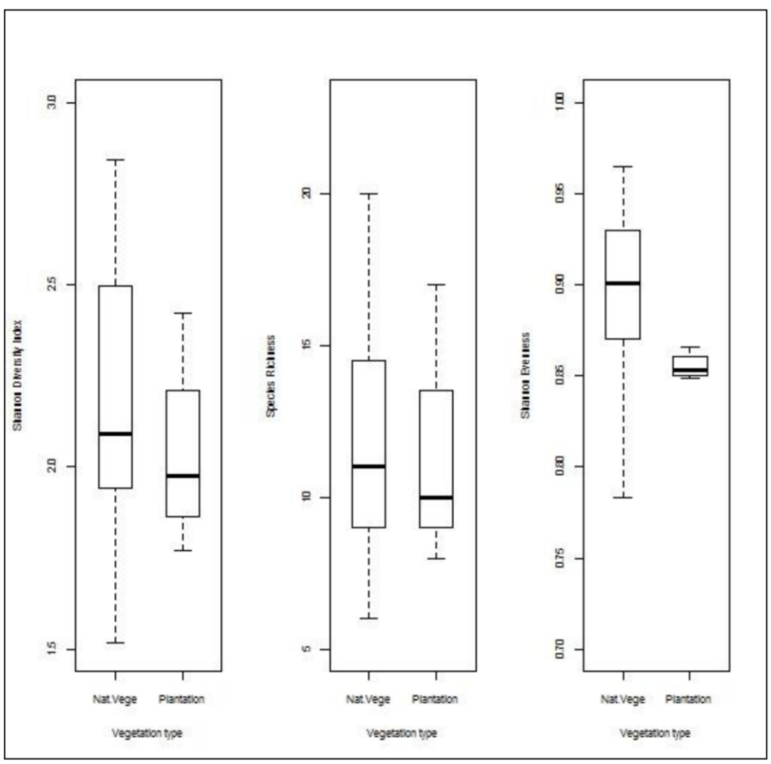

Figure 5. *Boxplot showing species richness, diversity and evenness of aboveground vegetation in Komto Forest*

Soil Seed bank flora

Fifty-two species (33 from 0-3cm depth, 29 from 3-6 cm depth, 27 from 6-9 cm depth and 21 from 9-12 cm depth) belonging to 46 genera, and 24 families were recorded from soil seed bank analysis of Komto Forest (Table 2).

Table 2

Abundance and composition of soil seed bank in different soil depths

S/N	Name of species	Family	Habit	Layer 1	Layer 2	Layer 3	Layer 4	Total	Seeds/m^2
1	*Abutilon logicuspe* Hochst.exA.Rich.	Malvaceae	Sh	7	0	0	0	7	700
2	*Achyranthes aspera* L.	Amaranthaceae	H	0	12	0	0	12	1200
3	*Acmella caulirhiza* Delile	Asteraceae	H	0	0	1	2	3	300
4	*Amaranthus hybridus* L.	Amaranthaceae	H	24	14	3	1	42	4200
5	*Bidens ghedoensis* Mesfin	Asteraceae	H	14	11	0	0	25	2500
6	*Bidens pilosa* L.	Asteraceae	H	22	10	9	0	41	4100
7	*Calpurnia aurea* (Ait.) Benth.	Fabaceae	Sh	4	0	0	0	4	400
8	*Ceropegia sobolifera* N.E.Br.	Asclepiadaceae	H	6	2	3	0	11	1100
9	*Clutia abyssinica* Jaub. &Spach.	Euphorbiaceae	Sh	0	0	0	1	1	100
10	*Commelina benghalensis* L.	Commelinaceae	H	0	9	0	2	11	1100
11	*Convolvulus arvensis* L.	Convolvulaceae	L	0	5	4	7	16	1600
12	*Conyza schimperi* Sch.Bip.ex A.Rich.	Asteraceae	H	0	0	0	3	3	300
13	*Crassocephalum macropappum* (Sch.Bip.exA.Rich.) S.Moore	Asteraceae	H	0	5	0	3	8	800
14	*Crepis foetida* L.	Asteraceae	H	7	0	0	4	11	1100
15	*Crotalria milbraedii* Bak.f.	Fabaceae	Sh	7	6	0	2	15	600
16	*Croton macrostachyus* Del.	Euphorbiaceae	T	35	13	7	5	60	6000
17	*Cyathula uncinulata* (Schrad.) Schinz.	Amaranthaceae	Sh	25	11	0	0	36	2500
18	*Cyperus distans* L.f.	Cyperaceae	H	16	0	2	4	22	2200
19	*Dichrocephala integrifolia*	Asteraceae	H	0	0	8	0	8	800
20	*Dombeya torrida* (J.F.Gmel.) P. Bamps	Sterculiaceae	T	0	18	3	0	21	2100
21	*Drymaria cordata* (L.) Schultes	Carryophyllaceae	H	9	0	0	0	9	900
22	*Echinops longisetus* A.Rich.	Asteraceae	Sh	0	6	0	0	6	600
23	*Eragrostis tef* (Zuccagni) Trotter	Poaceae	H	20	0	5	0	25	2500
24	*Eriosema longipedunculatum* A. Rich.	Fabaceae	H	12	5	0	0	17	1700
25	*Galinsoga parviflora*	Asteraceae	H	23	19	3	3	48	4800
26	*Girardinia bullosa* Wedd.	Urticaceae	H	63	35	21	3	122	12200
27	*Hibiscus calyphyllus* Cav.	Malvaceae	Sh	23	27	15	29	94	9400

S/N	Name of species	Family	Habit	Layer 1	Layer 2	Layer 3	Layer 4	Total	Seeds/m²
	Table 2 continues								
28	*Hibiscus vitifolius* L.	Malvaceae	Sh	3	0	3	0	6	600
29	*Hyparrhenia hirta* (L.) Stapf.	Poaceae	H	23	5	4	0	32	3200
30	*Hypoestes forskaolii* (Vahl) R.Br.	Acanthaceae	H	24	10	4	3	41	4100
31	*Impatience hochstetteri* Warb	Balsaminaceae	H	0	0	10	9	19	1900
32	*Kosteletzekya adoensis* (Hochest.exA.Rich.) Mast.	Malvaceae	Sh	0	15	7	5	27	2700
33	*Laggera crispata* (Vahl) Hepper & Wood	Asteraceae	H	24	20	3	0	47	4700
34	*Landolphia buchananii* (Hall.f.) Stapf.	Apocynaceae	L	4	0	0	0	4	400
35	*Maesa lanceolata*	Myrsinaceae	T	6	0	0	0	6	600
36	*Panicum hochstetteri* Steud.	Poaceae	H	21	0	1	0	22	2200
37	*Physalis peruviana* L.	Solanaceae	Sh	0	2	0	0	2	200
38	*Plantago lanceolata* L.	Plantaginaceae	H	0	9	0	0	9	900
39	*Plectranthus punctatus* L'Heirt	Lamiaceae	Sh	26	0	0	0	26	2600
40	*Rubia cordifolia* L.	Rubiaceae	H	0	6	1	0	7	700
41	*Rubus apetalus* Poir.	Rosaceae	Sh	0	3	0	0	3	300
42	*Rumex abyssinicus* Jacq.	Polygonaceae	H	0	0	3	0	3	300
43	*Satureja paradoxa* (Vatke) Engl.	Lamiaceae	H	0	0	0	4	4	400
44	*Solanum anguivi* Lam.	Solanaceae	Sh	22	5	2	0	29	2900
45	*Solanum incanum* L.	Solanaceae	Sh	0	0	6	0	6	600
46	*Solanum marginatum* L.	Solanaceae	Sh	0	0	0	8	8	800
47	*Solanum nigrum* L.	Solanaceae	Sh	25	0	0	0	25	2500
48	*Syzygium guineense* (Willd.) DC. ssp. *afromontanum* F.White	Myrtaceae	T	5	0	0	0	5	500
49	*Trifolium semipilosum* Fresen.	Fabaceae	H	22	12	11	3	48	4800
50	*Urtica simensis* Steudel	Urticaceae	H	106	40	11	9	166	16600
51	*Vernonia amygdalina* Del.	Asteraceae	T	26	0	0	0	26	2600
52	*Vernonia auriculifera* Hiern	Asteraceae	Sh	33	0	5	0	38	3800
	Total			687.00	335.00	155.00	110.00	1287.00	126700.00
	Mean			13.21	6.44	2.98	2.12	24.75	2436.54
	SD			18.58	9.09	4.42	4.54	30.45	3048.82

Among the species recovered from soil seed bank, most of them (53.85%) were herbs while woody plant species were only 24 (shrubs (17), trees (5), and lianas (2)) (Figure 6). *Landolphia buchananii*, and *Convolvulus arvensis* were the only lianas, and *Croton macrostachyus*, *Dombeya torrida*, *Maesa lanceolata*, *Syzygium guineense* and *Vernonia amygdalina* were the tree species observed in the soil flora. Asteraceae with 12 species (23.08%), and Solanaceae with 5 (9.62%) were abundant plant families in the soil seed bank of Komto Forest.

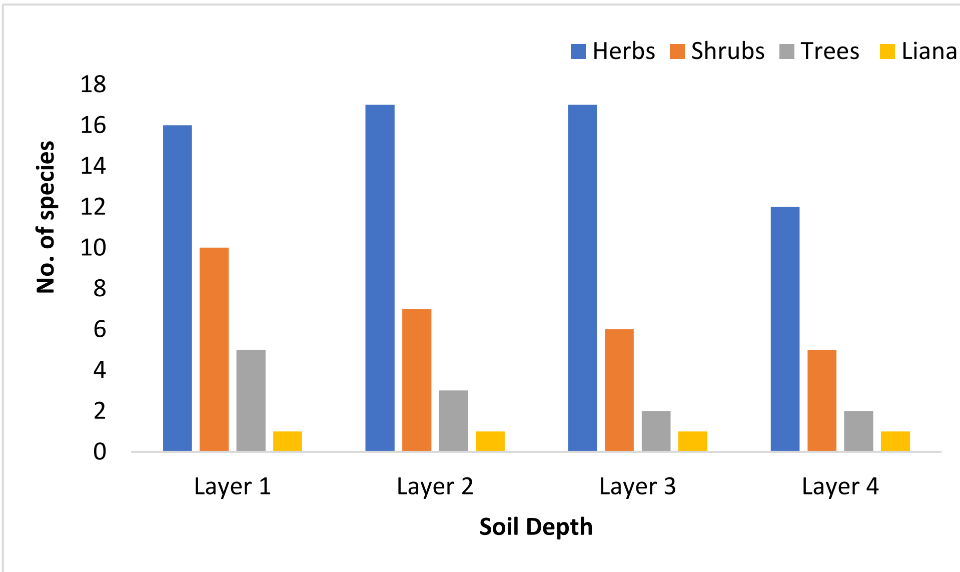

Figure 6. Bar plot showing growth forms and their respective number of species in four soil depths.

Soil seed bank flora in different depths ranged from 21 to 33 species with more species recovered from the upper layer. The four-sampling depth showed a significant difference in Shannon Weiner diversity index (H') (ANOVA, $F_{3, 104} = 45.74$, $p<0.001$) and in floristic richness (ANOVA, $F_{3, 104} = 48.35$, $p<0.001$) (Figure 7).

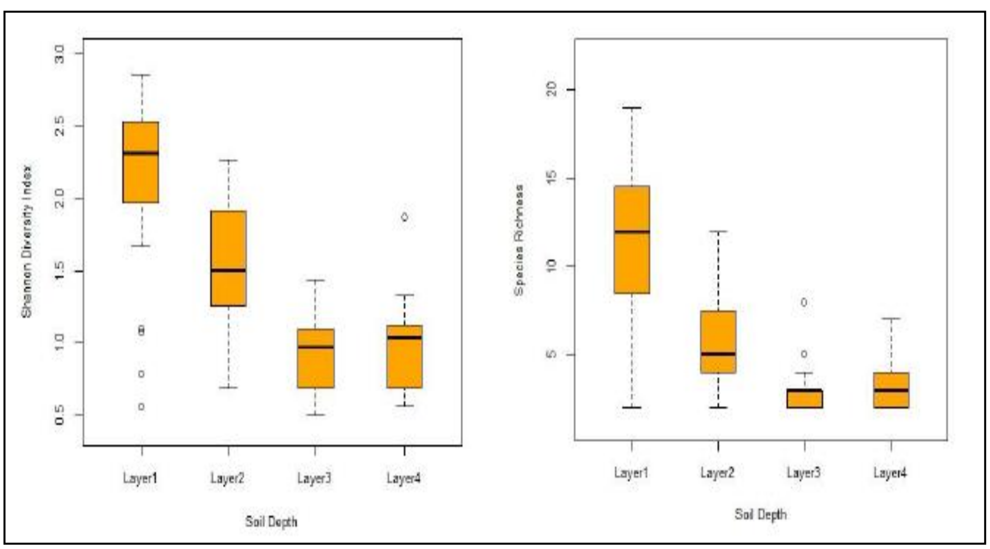

Figure 7. *Boxplot showing species richness and species diversity of SSB in the different soil depths*

Floristic Similarity among the different soil depth

Floristic similarity of the four different soil depths ranged from 0.32 (between the upper and bottom layers) to 0.59 (between the upper and 3rd layer). The second highest floristic similarity was between the 2nd and 3rd layers of soil depth, with a *Sj* = 0.58 (Table 3).

Table 3

Floristic similarity of soil seed banks between the different soil depths

Soil Depth (in cm)	0-3	3-6	6-9	9-12
0-3	1			
3-6	0.53	1		
6-9	0.59	0.58	1	
9-12	0.32	0.50	0.52	1

Soil seed bank and the standing vegetation shared only few species with Jaccarad coefficient of similarity (S_j) values ranging from 0.05 for the bottom layer to 0.16 for the upper layer (Table 4). Woody species namely, *Croton macrostachyus*, *Dombeya torrida*, *Vernonia auriculifera*, *Vernonia amygdalina*, *Syzygium guineense*, *Rubus apetalus*, *Maesa lanceolata*, *Solanum marginatum*, *Solanum anguivi*, *Kosteletzekya adoensis*, *Crotalria milbraedii*, *Landolphia buchananii*, *Abutilon logicuspe*, *Allophylus abyssinicus*, and few shrubs were recorded both in the standing vegetation and in the different depths of soil seed bank. However, the common forest tree species were absent in the soil seed bank. For instance, *Albizia gummifera*, *Apodytes dimidiata*, *Bersama abyssinica*, *Celtis africana*, *Ficus sur*, *Maytenus arbutifolia*, *Prunus africana*, *Sapium ellipticum*, *Teclea nobilis*, *Ricinus communis*, *Brucea antidysenterica*, and *Pouteria adolfi-friederici* are not recovered from the seed bank.

Table 4

Floristic similarity between aboveground flora and soil seed bank of the different depth

Soil depth	Shared Species	Unique to Aboveground flora	Unique to SSB	S_j Values
0-3 cm	13	60	19	0.16
3-6 cm	6	67	22	0.07
6-9 cm	6	67	20	0.07
9-12 cm	4	69	16	0.05

Soil Seed bank density along different depth

A total of 126, 700 seedlings with a mean value of 2475 ± 3044.88 seeds per m^2 were emerged from the four layers of the twenty-seven plots.

The number of seeds in the soil ranged from 100 seeds per m^2 for *Clutia abyssinica* to 16,600 per m^2 for *Urtica simensis* Steudel. Like that of species richness, mean seed density declines with increasing depth, with the top layer (0-3 cm) having more seeds, followed by 2nd, 3rd and 4th layers, respectively (Figure 8).

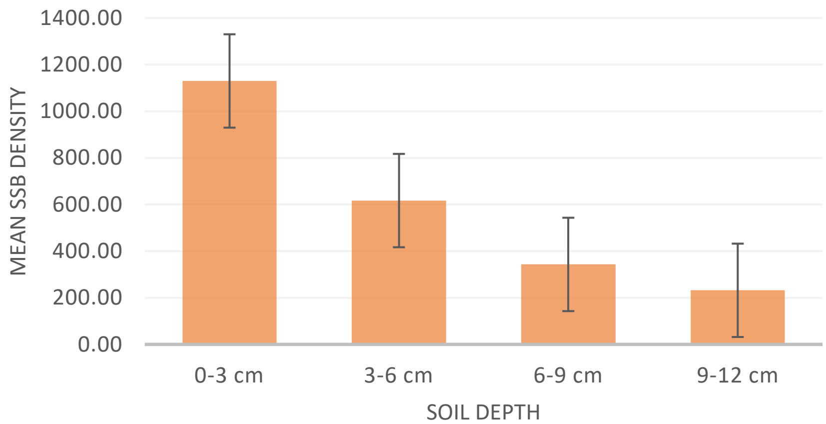

Figure 8. *SSB density in different soil depths.*

Similar to species diversity and richness, the four-sampling depth showed a significant difference in mean soil seed bank density (ANOVA, $F_{3,\ 104}$ =24.81, p<0.001), with the highest seed observed in the 0 to 3 cm soil layer (Figure 9). However, natural vegetation and the adjacent plantation forests did not show significant difference in soil seed bank density ($F_{1,\ 106}$ =1.55, p>0.05).

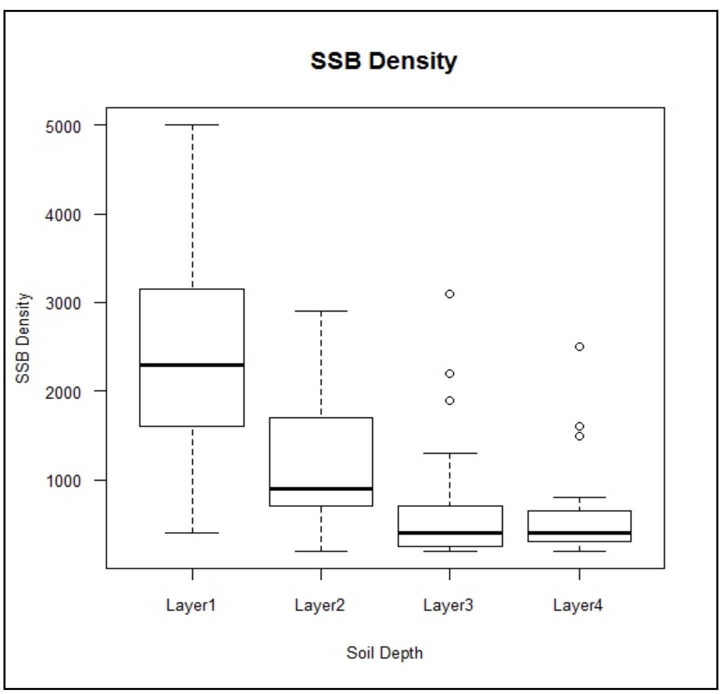

Figure 9. *Mean difference in SSB density of Komto Forest*

In Komto Forest, few species contributed the majority of soil seed bank. Accordingly, 56.42% of the total viable seeds were contributed by 10 species (Table 5). The most abundant species were *Urtica simensis*, *Girardinia bullosa*, *Hibiscus calyphyllus*, *Croton macrostachyus*, *Trifolium semipilosum*, *Laggera crispata*, *Amaranthus hybridus*, *Bidens pilosa*, *Hypoestes forskaolii*, and *Vernonia auriculifera*.

Table 5

Abundant species in Soil Seed bank (seeds/m^2)

S/N	Name of species	Family	Habit	Layer 1	Layer 2	Layer 3	Layer 4	Total
1	*Urtica simensis* Steudel	Urticaceae	H	4600	5000	4100	2900	16600
2	*Girardinia bullosa* Wedd.	Urticaceae	H	6300	3500	2100	300	12200
3	*Hibiscus calyphyllus* Cav.	Malvaceae	Sh	2300	2700	1500	2900	9400
4	*Croton macrostachyus* Del.	Euphorbiaceae	T	2500	1900	700	900	6000
5	*Trifolium semipilosum* Fresen.	Fabaceae	H	2200	1200	1100	300	4800
6	*Laggera crispata* (Vahl) Hepper & Wood	Asteraceae	H	2400	2000	300	0	4700
7	*Amaranthus hybridus* L.	Amaranthaceae	H	2400	1400	300	100	4200
8	*Bidens pilosa* L.	Asteraceae	H	2200	1000	900	0	4100
9	*Hypoestes forskaolii* (Vahl) R.Br.	Acanthaceae	H	2400	1000	400	300	4100
10	*Vernonia auriculifera* Hiern	Asteraceae	Sh	3300	0	500	0	3800

Discussion

Species Diversity of Aboveground Vegetation

This study revealed 74 woody plant species. This figure is much less than the 103 woody species reported in the previous study (Fekadu et al., 2012). This could be due to excessive exploitation of the forest by the surrounding community for both fuel and construction purposes. But it was higher than that of Hugumbirda Forest (Degafi & Berhanu, 2014).

Soil seed banks: Soil seed banks are considered as a cost effective alternative in forest management systems as they play a significant role in the restoration of degraded lands. A soil seed bank study in Komto moist forest revealed 52 species that represent 45 genera and 24 families. Asteraceae (21.57%) and Solanaceae (9.80%) were most abundant. The reason for the dominance of Asteraceae in SSB could be associated with small, abundant and light-weight seeds that are easily dispersed and can easily enter the soil seed bank either via cracks in the soil or being carried by insects (Harper, 1977; Hong et al., 2012). The number of species obtained in this study is more or less similar to the findings of Feyera and Demel (2002) from Munessa-Shashemene forest and that of Mebratu (2019) from Wejig-Mahgo-Waren forest, northern Ethiopia, but much greater than that of Harenna Forest (Getachew et al., 2004). The large majority of the species (53.85%) were herbs. This is in line with the findings of Benvenuti (2007) in which he indicated that the small seed size of herbaceous plants helps them to easily incorporate into the soil and form a seed bank. The lower susceptibility of herbaceous seeds to predation also contributed to their abundance in the soil (Thompson, 1987; Guo et al., 1998; Luzuriaga et al., 2005). Previous studies in Ethiopia and elsewhere (Feyera and Demel, 2001 and 2002; Ericksson et al., 2003; Kebrom & Tesfaye, 2006; Alemayehu Wassie, 2007; Mebratu Hishe, 2019), with the exception of Getachew et al. (2004), also reported a similar result in which herbaceous species dominated soil seed banks. Decocq et al. (2004) and Daws et al. (2005) also indicated that herbs remain viable for a long time even when the environmental conditions are unfavourable, unlike tree species with large seeds that tend to lose viability immediately after seed fall.

Although the seedling emergence method can significantly underestimate seed bank density because seeds have specific environmental requirements to germinate (Gonzalez & Ghermandi, 2012), several woody species in Komto Forest did not have long-lived viable seeds in the soil. In this study, only five (17.24%) out of the 29 tree species in the aboveground vegetation were represented in the soil seed banks, asserting that the soil seed bank in Komto Forest is poor in seeds of tree species. Mulugeta and Demel (2006) also found only 6 tree species out of 66 species in the dry Afromontane forests of Ethiopia. Despite the fact that widespread and invasive species are well represented in the soil seed bank and can be restored from persistent seed banks, most endangered species lack viable seeds in the soil and cannot be restored from seed banks alone (Bossuyt and Honnay, 2008). In line with this, tree species in Komto moist forest had few viable seeds, which might be due to the humid, moist climate that favours rapid germination and depleted soil seed bank. Seeds of woody plant species are transient and germinate within a few days of their dispersal, so their seeds are less likely to be stored in the soil.

According to Kebrom and Tesfaye (2006), trees in the Afromontane forests depend on abundant seedlings and their ability to grow from coppicing. The deficiency of woody species in the soil seed bank of Komto Forest may be due to either the removal of seed-producing mother trees for fuel, construction, and timber or the depletion of gap specialists and pioneer tree species (Saatkamp et al., 2014). This implies that natural forest restoration from soil seed banks alone would be difficult (Alemayehu Wassie, 2007). This is in line with the conclusions of previous studies (Ericksson et al., 2003; Mulugeta and Demel, 2006; Alemayehu Wassie, 2007). Thus, woody species in Ethiopian vegetation are highly threatened, and their continuous existence will be possible only through strict conservation of the few remnant natural forests that will serve as seed sources (Feyera and Demel , 2002). Similarly, in addition to conserving the few remnant mother trees in the area, enrichment planting with seedlings of indigenous tree species raised on nursery sites and exclosure for natural restoration are vital to save Komto Forest before it is irreversibly damaged. The low Jaccarad coefficient of similarity between soil seed banks and aboveground flora confirms the weak contribution of soil seed banks to replace the standing vegetation. Rapid seed germination due to the humid, hot climate of the study area or loss of seeds to predators and some mechanical damages could be the reason for the weak association (Kebrom & Tesfaye, 2006). Similar results were reported by previous studies (Perera, 2005; Uasuf et al., 2009). Hence, soil seed banks are not sufficient for the natural restoration of Komto Forest, asserting the need for enrichment planting.

The vertical distribution of seeds across the different soil layers showed great variation. Floristic richness and the number of seeds showed a declining trend with increasing soil depth. As per this study, seeds of forest trees were observed in the upper few cm of soil depth. For instance, the seeds of *Croton macrostachyus*, *Syzygium guineense* ssp. *afromontanum*, *Dombeya torrida*, *Vernonia amygdalina,* and *Maesa lanceolata* were restricted to 0–6 cm of the soil depth, asserting that seed longevity, seed size, mode of seed dispersal, and seed predation are significantly affecting soil seed bank distribution in the soil. The difference in soil physical characteristics such as soil texture and structure could also contribute to the variation in vertical distribution of seeds in the soil (Tefera et al., 2005). Alemayehu Wassie (2007) also stated that having small and light-weighted seeds that are easier for long-distance dispersal made some plant species dominant in the soil.

Seed density and its vertical distribution in the soil stratum

Available evidence indicates that late-successional woody species are hardly observed in the soil seed bank because they produce recalcitrant seeds that germinate immediately after their disturbance; hence, they do not accumulate in seed banks (Zobel et al., 2007). Bossuyt and Honnay (2008), on the other hand, confirmed that early successional or invasive species are more abundant and dominant in the soil seed bank than late successional tree species. Comparison of seed density in the current finding with other similar studies showed that mean seed density in Komto Afromontane moist forest (2475 seeds per m^2) was more or less equivalent to that of Dega Damot District (2133 seeds per m2) (Liyew Berhanu *et al.*, 2022) and considerably higher than Harenna Forest (622 seeds per m^2) (Getachew et al., 2004) and the mixed coniferous forest stands (Zobel et al., 2007) but much lower than the 12,300 and 13,700 seeds per m^2 in Menagesha and Munessa forests, respectively (Feyera and Demel, 2002). A number of factors are responsible for the low soil seed bank density in Komto Forest. Availability of seed sources, sampling intensity, successional stages of the forest, and the techniques employed (the seedling emergence method, which dramatically underestimates soil seed bank density) are some of the reasons (Getachew et al., 2004). Other reasons, including high seed mortality and the use of seedling bank strategies or coppices as a major regeneration route for some tree species, may also be responsible for the difference in seed bank density (Swaine and Whitmore, 1988; Whitmore, 1993; Demel, 1995). Komto Forest was known to possess abundant young seedlings in the understory (Fekadu et al., 2012).

This study also showed significant variation in seed density across different soil depths. That is, as depth increased, the number of seeds decreased remarkably. This is in line with the findings of Abdella et al. (2007), where they observed high seed density in the top soil layer (0–3 cm) because recently dispersed seeds are not yet transported to the lower soil depth or due to organic matter accumulation on the surface (Putwain and Gillham, 1990). On the other hand, a decrease in viability with increasing soil depth may contribute to little success in germination and could be the reason for lower seed density with increasing soil depth (Baskin and Baskin, 1998). The low floristic similarity between soil seed banks and the aboveground vegetation is consistent with other similar studies, such as Alemayehu Wassie (2007). The reasons for this could be, perhaps, rapid seed germination after dispersal due to a warm, moist climate or loss of viability due to genetically controlled traits. Unlike long-lasting herbaceous seeds, those species with transient seeds survive only for a brief period in soils.

CONCLUSIONS

Previous studies on Komto Forest revealed rich woody plant species (Fekadu et al., 2012). The current study, however, showed fewer species in the aboveground vegetation, asserting unabated anthropogenic impacts including grazing by livestock, charcoal production, and cutting trees to get wood for fuel, construction, and timber. Although Thompson (1992) and others agree that soil seed banks provide seeds for the restoration of the original vegetation after disturbance, it varies depending on several variables, including the degree of anthropogenic impacts. The current study on Komto Forest showed that herbaceous species dominated the soil flora, and the upper 3 cm soil has higher species and seed density than the successive soil depths. The dominance of herbaceous species is attributed to the ability of herbaceous plants to produce numerous, small-sized, and lightweight seeds that can be easily dispersed (Savadogo et al., 2016). The reduction in perennial vegetation following disturbance also favours annual and perennial forbs and graminoids via reduced competition and easy access to light (Savadogo et al., 2016).

In this study, woody species are few, with only five tree species recovered from the germination trial (Price et al., 2010). Indigenous forest trees, namely *Albizia schimperiana*, *Prunus africana*, *Pouteria adolfi-friederici*, *Cordia africana*, *etc.*, were missing from the seed bank, asserting that forest restoration by natural regeneration is unlikely in Komto Forest. This suggests hampered regeneration of the common forest trees by different factors, including lack of mother trees that can serve as a seed source for tree species that use seed rain as the main regeneration strategy (Bewley et al., 1994), or some tree species may depend on coppicing from stumps (Feyera & Demel, 2002). Large mother trees were hardly observed in Komto Forest, indicating a limitted seed rain to enrich the soil seed bank. Hence, soil seed bank alone is not sufficient for the rehabilitation of Komto Forest.

Moreover, as single-period seed bank sampling may miss some transient species, periodic assessment of soil seed bank dynamics is vital in the future. The insufficient number of native forest tree species in the soil seed indicates forest restoration from the soil seed bank is not sufficient in Komto Forest. So, rehabilitation approaches that combine enrichment planting of threatened indigenous plant species, such as *Albizia schimperiana*, *Prunus africana*, *Cordia africana*, *Pouteria adolfi-friederici*, *Ficus sur*, *etc.*, with passive restoration techniques, such as area enclosures, are vital. Introducing participatory forest management programmes and engaging the local people in forest rehabilitation activities is also vital in Komto Forest. Finally, providing alternative eco-friendly livelihood strategies such as honey production, poultry farming, and diversified agroforestry practices for local communities living around Komto Forest may lessen the anthropogenic burden on the forest.

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DECLARATION

The authors declare that they have no competing interests

DATA AVAILABILITY STATEMENT

Data sets generated during the current study are available from the corresponding author on reasonable request.

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