SOIL SEED BANK COMPOSITION AND ITS IMPLICATIONS FOR DRY WOODLAND RESTORATION IN ARGO FOREST, BENA-TSEMAY DISTRICT, SOUTHERN ETHIOPIA

Melese Bekele Hemade*
Forest and Range land Plant Biodiversity Research Lead Executive, Ethiopian Biodiversity Institute, Addis Ababa, Ethiopia

ABSTRACT: Soil seed banks are critical for the natural regeneration of degraded dryland forests. This study provides the first comprehensive assessment of the soil seed bank in the Argo Forest, Bena-Tsemay District, Southern Ethiopia. The study quantified the composition, density, and vertical distribution of the soil seed bank and evaluated its potential for spontaneous vegetation recovery across four land-use types (grassland, woodland, bushland, and bare land) and three soil depths (0–3 cm, 3–6 cm, and 6–9 cm). A total of 84 composite soil samples were collected and subjected to an eight-month greenhouse germination assay. The total seed bank density was 8,232 seedlings m^{-2}. The outcome showed a distinct vertical gradient: species richness and seedling density peaked in the top layer (0–3 cm) and sharply declined with depth. Using Jaccard's and Sørensen's indices, floral similarity was lowest between woodland and bare land (0.16) and highest between grassland and bushland (0.48). Importantly, Analysis of variance, ANOVA revealed a significant difference ($p < 0.001$) between the species composition of the established above-ground flora and the soil seed bank. This stark difference suggests that the in-situ seed bank's ability to support the restoration of the original woody ecosystem is severely limited. As a result, it concludes that passive restoration relying solely on the soil seed bank is unlikely to be sufficient. Active interventions, specifically enrichment planting of native woody species and the implementation of stringent controlled grazing regimes, are essential to accelerate ecological restoration in this dry Afromontane forest.

Keywords/Phrases: Density, Ecological restoration, herbaceous dominance, Seedlings, Vertical seed distribution,

* Corresponding author: melesebekeles@gmail.com

INTRODUCTION

Dryland ecosystems, encompassing arid, semi-arid, and dry sub-humid regions, represent one of the planet's most expansive and fragile biomes, covering over 40% of the global terrestrial surface (Cherlet et al., 2018). These ecosystems are vital for biodiversity, carbon storage, and the livelihoods of over two billion people globally. Nonetheless, they are increasingly being recognized as centers for desertification and land degradation because of the combined effects of unsustainable human activity and climate change (IPBES, 2018). Ethiopia's drylands, which are undergoing rapid ecological change that threatens both environmental stability and socioeconomic resilience, are a notable instance in this global setting.

The vast dryland areas of Ethiopia are particularly susceptible to increasing climate variability, which can show up as frequent droughts, unpredictable rainfall patterns, and rising temperatures (Conway and Schipper, 2011). The rich mosaic of native flora and fauna that communities rely on is being undermined, rain-fed agriculture is becoming unstable, and water supplies are being depleted as a result of these climate shocks (Sintayehu, 2018; Gezie, 2019; Bogale and Erena, 2022). Anthropogenic stresses, especially unsustainable livestock populations and related overgrazing, exacerbate this climate stress throughout the nation's vast pastoral and agro-pastoral systems (Angassa and Oba, 2008). Large tracts of formerly productive rangelands have been reduced to bare, compacted soil by the ensuing feedback loop, seriously impairing plant communities' natural recruitment, survival, and population dynamics (Zerga et al., 2018). This degradation challenges not only ecological integrity but also the very foundation of pastoral livelihoods, triggering a cycle of poverty and resource depletion (Desta and Coppock, 2004).

Notably, the visible aboveground vegetation is only one aspect of the adaptability and survival of a plant community. The soil seed bank (SSB), a mysterious but essential basement legacy, runs parallel to this. A key element of ecosystem memory, this store of viable, dormant propagules retains the genetic capacity for future recovery while capturing the imprint of previous vegetation (Baskin & Baskin, 2000). By allowing populations to endure adverse times, promoting secondary succession following disturbance, and preserving genetic variety within the landscape, the SSB serves as a defensive buffer against environmental fluctuation (Davy, 2008; de Medeiros-Sarmento et al., 2021). As a result, it is essential to ecological resilience and a crucial factor in determining a system's inherent capacity to recover after degradation (Walck et al., 2011).

The Argo Natural Forest in the Bena-Tsemay district of southern Ethiopia is a prime instance of the ecological significance of the SSB. This environment, which is an array of dry woodland and savanna, is an essential socio-ecological refuge. For the local populations, it offers vital resources such fuel wood, fodder, non-timber forest products, and traditional remedies (Lemenih and Kassa, 2014). However, multiple anthropogenic pressures continuous and frequently uncontrolled grazing, shifting fire regimes, and land conversion for other uses are posing an increasing threat to this lifeline. By reducing seed output, raising seed predation, and changing the soil microenvironment required for seed survival, these disruptions directly endanger the SSB (Wang et al., 2009). Consequently, the depletion of this belowground reservoir directly constrains the ecosystem's innate capacity for natural regeneration. It needs active treatments like planting or seeding because it lacks target species and is dominated by weeds (Bossuyt and Honnay, 2008). However, a diverse native SSB increases climate resilience and speeds up recovery (Warrier and Kunhikannan, 2022).

This research was therefore designed to establish the foundational scientific sympathetic of the soil seed bank (SSB) within the drought-vulnerable Argo Forest, where no prior representation exists. The study addresses this critical gap through three integrated objectives: first, to quantify the floristic composition, density, and vertical distribution of the SSB across the ecosystem's dominant land-use types; grassland, woodland, bushland, and bare land. Second, to assess the degree of floristic similarity between the SSB and the standing aboveground vegetation, a key determinant of regeneration potential. Finally, by synthesizing these empirical findings, the study formulates evidence-based recommendations that critically evaluate the feasibility of passive natural regeneration versus the necessity for active, targeted restoration interventions. This work provides the essential data required to guide effective biodiversity conservation and sustainable forest management strategies for this imperiled dryland ecosystem.

MATERIALS AND METHODS

Study Area

The Argo Forest is located in the Bena-Tsemay District of Ethiopia's Southern Nations, Nationalities, and Peoples' Region, between 05°31′30″–05°37′00″ N and 36°40′30″–36°50′30″ E. Over 80% of the district is characterized by a dry, semi-arid agro-ecology, with the town of Keye Afer experiencing mean annual temperatures ranging from 16°C to 40°C and highly erratic rainfall between 260 and 570 mm. The broader landscape is rugged and undulating, with district elevations varying from 560 to 2300 m above sea level, though the forest is situated primarily between 1400 and 2000 m. This topographical diversity has adopted a variety of soil types, predominantly brown (60%), followed by black (30%) and reddish (10%) soils, which collectively underpin the forest's ecological dynamics (Figure1).

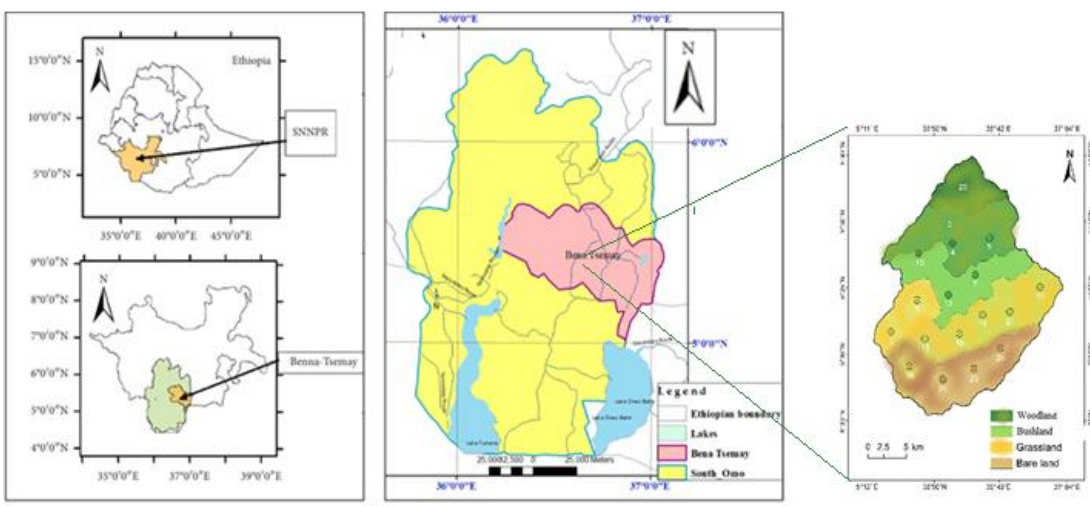

Figure 1. Map of the study area

Design and Methods of Data Collection

This research employed a stratified random sampling design to evaluate the soil seed bank (SSB) across the dominant land-use mosaic of the Argo Forest. The study area is characterized by a vegetation assemblage of grassland, woodland, bushland, and bare land, influenced by anthropogenic activity and grazing. Dominant woody vegetation includes *Combretum-Terminalia* and *Acacia-Commiphora* woodland types, with semi-desert scrubland at lower altitudes. To systematically capture spatial heterogeneity driven by vegetation structure and disturbance regimes, the landscape was classified into four distinct land-use strata based on established definitions: Grassland (herbaceous, grazed), Woodland (scattered trees/shrubs over a grassy understory), Bushland (dense shrubs and small trees with limited ground cover), and Bare land (erosion-prone, sparse or no vegetative cover).

Within each of these four strata, seven main sampling plots were systematically established, totaling 28 plots, each measuring 20 m × 20 m. At each main plot, soil sampling was conducted at five predetermined sub-points: four at the plot corners and one at the center. To assess the vertical distribution of soil seed bank (SSB), samples were systematically collected from a total of 140 points (28 plots × 5) using a sharp knife and spoon across three successive depth intervals: 0–3 cm, 3–6 cm, and 6–9 cm. Following standardized protocols, the five samples from each identical depth layer within a single main plot were thoroughly homogenized to form a single composite sample per depth per plot. This compositing procedure resulted in a final analytical dataset of 84 composite soil samples (28 plots × 3 depths), which were then processed for seed germination trials to determine species composition, density, and viability across the defined land-use and depth gradients (Figure 2)

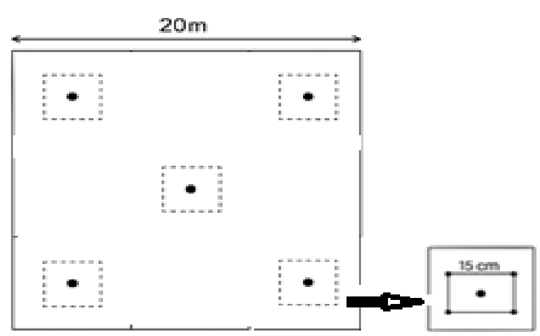

Figure 2. Design of the soil seed bank sampling

Following collection, each composite soil sample was transported to a controlled greenhouse facility at Addis Ababa University for processing. Samples were first sieved through a 2 mm mesh to remove coarse debris, with any seeds retained on the sieve subsequently reintroduced to the fine soil fraction. The seed germination analysis was conducted using the direct germination method, wherein each prepared sample was spread evenly in a labeled plastic tray. Trays were maintained under greenhouse conditions with daily watering. The germination trial was monitored continuously for a period of eight months to ensure maximal seedling emergence, aligning with established protocols for capturing both immediate and dormant seed populations. To prevent competition and shading, all clearly identifiable seedlings were systematically recorded, identified to species level where possible, counted, and then removed from the trays following the methodology used by Dollery (2017). Furthermore, the seedlings that could not be identified in the greenhouse were examined at the Ethiopian National Herbarium (Addis Ababa University) through comparison with authenticated specimens. This meticulous protocol allowed for the accurate quantification of viable seed density and floristic composition within the soil seed bank (Figure 3).

Figure 3. Soil seed bank samples and greenhouse germination

Data Analysis

The data generated from the eight-month seedling emergence trial were subjected to comprehensive statistical analysis to characterize the soil seed bank's composition, structure, and relationship with standing vegetation. The analysis focused on core ecological metrics; species richness, seedling density (reported as seeds m^{-2} for both cumulative and depth-specific values), and diversity. To determine significant differences in soil seed bank attributes among four land-use types (grassland, woodland, bushland, and bare land) and across three soil depths (0–3 cm, 3–6 cm, and 6–9 cm), a one-way analysis of variance (ANOVA) was performed using SPSS software (Version 20). This tested the main effects of land-use type and soil depth, as well as their interaction. Where significant effects were detected, post-hoc comparisons were conducted using Tukey's Honestly Significant Difference (HSD) test at a 95% confidence level ($p < 0.05$). Floristic similarity was assessed using two established coefficients; the Jaccard similarity index was employed to quantify compositional overlap between different land-use types and soil layers:

$$\mathbf{Sj} = \frac{\mathbf{a}}{\mathbf{a} + \mathbf{b} + \mathbf{c}}$$

Where Sj = Jaccard similarity coefficient

a = Number of species common to both land use types/ soil layers

b = Number of species unique to land use type b / soil layer b.

c = Number of species unique to land use type c/ soil layer c. The coefficient has a value from 0 to 1, where 1 indicates complete similarity and 0 shows a complete dissimilarity.

While the Sørensen similarity index was used to evaluate the degree of floristic similarity between the soil seed bank and the standing aboveground vegetation based on (Levassor *et al*., 1990) by using Sorenson index (SI) by the formula:

$$\mathbf{Ss} = \frac{\mathbf{2C}}{(\mathbf{2C} + \mathbf{a} + \mathbf{b})}$$

Where Ss= Sørensen Coefficient of similarity, C= the number of species found in both the soil seed bank and the standing vegetation, a is the number of species in the soil seed bank and b is the number of species in the standing vegetation. The coefficient may be 0 to 1 which stands for no similarity or full similarity respectively (Peco et al., 1998).

The vertical distribution of seeds was explicitly analyzed to describe stratification patterns, detailing shifts in density and species composition with increasing soil depth. This multi-faceted analytical approach provided a robust quantitative foundation for evaluating natural regeneration potential and informing management recommendations.

RESULTS

Soil seed bank composition and density

From the soil seed bank of the Argo forest, 62 species, belonging to 48 genera and 29 plant families, were recorded. The Poaceae family was the most prevalent in the soil seed bank, comprising roughly 22% of all species recovered. Asteraceae (17%), Fabaceae (10%), and Solanaceae (5%) were the next most abundant families, ranking second to fourth, respectively. As a result, about 54% of the species recovered from the soil seed bank in the area comprised these four most prevalent plant families. Herbs were the dominant life form, accounting for 76% of species, followed by shrubs (19%), trees (2.6%), and climbers (2.4%) respectively (Figure 4).

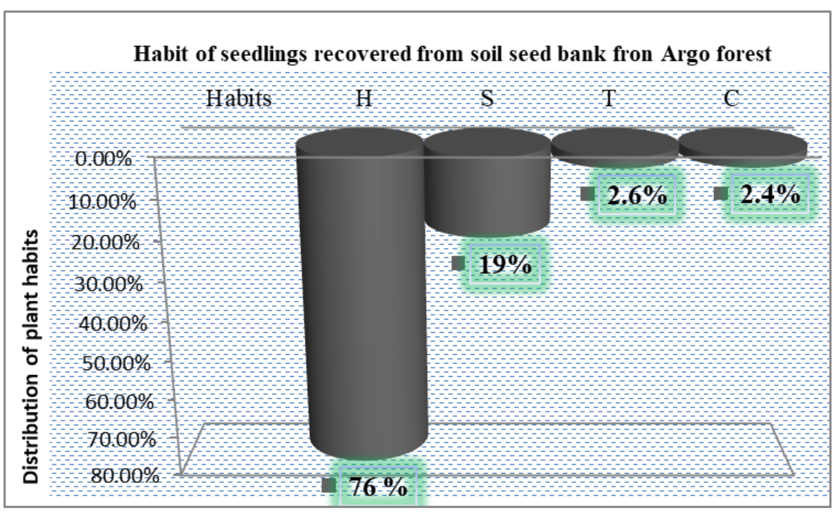

Figure 4. Habits of plant species recovered from soil seed bank in Argo forest.

The ten most dominant species recorded in the study area were *Hyparrhenia pilgeriana* (11%), *Pennisetum petiolare* (9%), *Eleusine floccifolia* (8.7%), *Senna occidentalis* (8%), *Senna petersiana* (7.4%), *Alchemilla abyssinica* (7.1%), *Digitaria ternata* (6.6%), *Cynoglossum lanceolatum* (6.3%), *Oxalis procumbens* (5%), and *Pennisetum thunbergii* (4.8%). Together, these species accounted for approximately 74% of the total frequency in the area, indicating their ecological dominance in the soil seed bank.

Woody species recovered from the soil seed bank included *Acacia seyal*, *Indigofera articulata*, *Calpurnia aurea*, *Olea europaea* subsp. cuspidata, *Rhus natalensis*, *Solanum incanum*, *Dodonaea angustifolia*, *Senna petersiana*, *Croton macrostachyus*, and *Solanum marginatum*.

Species composition varied across land-use types. Grassland exhibited the highest species richness (49 species), followed by bushland (42 species); bare land had the lowest richness (33 species). Seedling density showed a similar pattern: grassland supports the highest density (3316 m^{-2}), followed by woodland (2251 m^{-2}) and bushland (1869 m^{-2}), with bare land showing the lowest density (796 m^{-2}).

Vertical distribution of the soil seed bank revealed that the uppermost soil layer consistently contained the highest seedling density across all land-use types. The uppermost soil layer contributed the largest proportion of seedlings, whereas the deepest layer contained the fewest (Figure 5).

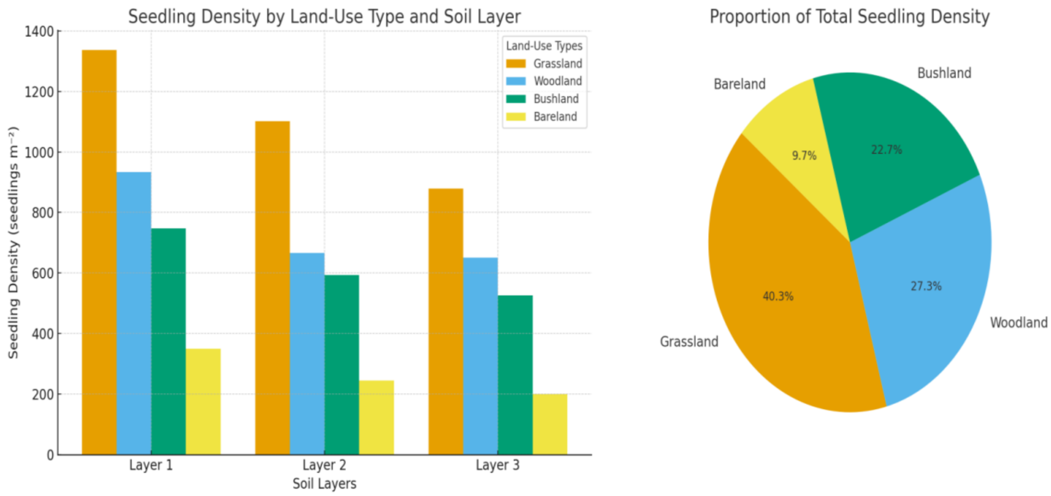

Figure 5. Comparison of seedling density across soil layers and land-use types (Left) and proportion of total seedling density contributed by each land-use type (Right).

Species Frequency by Land Use Type

Seedling frequency data across land-use types showed notable variation in species distribution. In grassland, the most frequent species were *Eleusine floccifolia*, *Hyparrhenia pilgeriana*, *Pennisetum petiolare, Alchemilla abyssinica*, *Argemone mexicana*, *Digitaria ternata*, *and Poa schimperiana*, which together accounted for 44% of the total frequency in this land use type.

Cynoglossum lanceolatum, *Dodonaea angustifolia*, *Galinsoga parviflora*, *Rhus natalensis*, *Bidens pilosa*, *Laggera crispeta*, *Torilis arvensis*, and *Solanum marginatum* were the most frequent species in the woodland soil seed bank, together representing approximately 30% of the total frequency for this land use type. In contrast, the least frequent species *Alchemilla abyssinica*, *Ageratum conyzoides*, *Artemisia abyssinica*, *Argemone mexicana*, and *Solanum marginatum* each contributed less than 1% to the total frequency in this land use type.

Bushland was dominated by *Solanum incanum*, *Acacia seyal*, *Senna occidentalis*, *Caylusea abyssinica*, *Indigofera articulata*, *Ocimum gratissimum*, and *Leucas martinicensis*. In contrast, *Dodonaea angustifolia*, *Rhus natalensis*, and *Bidens pilosa* exhibited the lowest frequencies in this habitat.

Conversely, the most frequent species on bare land were *Alchemilla abyssinica*, *Bidens pilosa*, *Argemone mexicana*, *Ageratum conyzoides*, *Eleusine floccifolia*, and *Hyparrhenia pilgeriana*. Most species common in other land-use types were either rare or entirely absent on bare land.

Species Composition and Similarity across Land Uses and Soil Layers

The soil seed bank analysis revealed a vertical stratification of species. Several woody species were restricted to the upper soil layer, including: *Acacia seyal*, *Euclea divinorum*, *Calpurnia aurea*, *Grewia bicolor*, *Croton macrostachyus*, *Olea europaea* and *Solanum marginatum*

Species shared between the first and second soil layers included *Crotalaria incana*, *Dodonaea angustifolia*, *Linum usitatissimum*, *Rhus natalensis*, *Senna occidentalis*, *Vernonia amygdalina*, *Solanum incanum*, and *Senna petersiana*. Overall, most woody species were confined to the first two layers, while herbaceous species were distributed throughout all three soil layers.

Jaccard's similarity coefficient (JCS) analysis revealed distinct patterns in species composition across both land-use types and soil seed bank layers.

Among land-use types, grassland and bushland exhibited the highest floristic similarity (JCS = 0.48), followed closely by woodland and bushland (JCS = 0.43). In contrast, the lowest similarity was found between woodland and bare land.

A similar analysis of the soil seed bank showed the highest species similarity between the first and second soil layers (JCS = 0.68). The similarity between the second and third layers was moderate (JCS = 0.42), while the first and third layers shared the least number of species (JCS = 0.36). The Jaccard's Similarity Coefficient (JCS) Values were specified (Table 1 a & b).

Table1 a. Similarity between land-use types

Land Use Type	Grassland	Woodland	Bushland	Bare Land
Grassland	—	0.41	0.48	0.27
Woodland		—	0.43	0.16
Bushland			—	0.18
Bare Land				—

Table 1b. Similarity between soil seed bank layers

Soil Layer	Layer 1	Layer 2	Layer 3
Layer 1	—	0.68	0.36
Layer 2		—	0.42
Layer 3			—

To assess the similarity between the soil seed bank and the standing vegetation across different land-use types, both Jaccard’s Coefficient of Similarity (JCS) and Sørensen’s Similarity Index (SI) were calculated based on species composition. In grassland areas, 22 species were exclusive to the soil seed bank, 50 spices were unique to the aboveground vegetation, and 13 species were shared, resulting in a JCS of 0.153 and an Ss of 0.265. Woodland areas had 26 species exclusive to the soil seed bank, 48 to the standing vegetation, and 15 common species, yielding a JCS of 0.169 and an Ss of 0.288. In bushland, 27 species were found only in the soil seed bank, 60 were exclusive to the standing vegetation, and 17 were common to both, resulting in a JCS of 0.163 and an Ss of 0.281. Among the three land-use types, woodland showed the highest similarity between the soil seed bank and standing vegetation, as indicated by both indices (Table 2).

Table 2. Jaccard's and Sørensen Coefficient of similarity between species composition of soil seed bank and the above ground vegetation

Land-Use Type	Exclusive to Seed Bank (A)	Exclusive to Standing Flora (B)	Shared Species (C)	JCS	Ss
Grassland	22	50	13	0.153	0.265
Woodland	26	48	15	0.169	0.288
Bushland	27	60	17	0.163	0.281

A one-way analysis of variance (ANOVA) revealed a statistically significant interaction between land-use type and vegetation component on species richness ($p < 0.001$), indicating that the difference in species richness between the soil seed bank and standing vegetation varied significantly across land-use types. Post-hoc comparisons using Tukey's HSD test showed that species richness in the standing vegetation was significantly higher than in the soil seed bank across all land-use types. Notably, standing vegetation in bushland exhibited the highest species richness, which was significantly greater than all other land-use and vegetation groups ($p < 0.05$). However, no significant differences in species richness were observed among the soil seed bank groups across land-use types (Table 3).

Table 3. Analysis of variance (ANOVA) showing a significant difference in composition between land use types of seed bank and standing vegetation (sig. at $p < 0.05$)

Comparison	Mean Difference	p-value	Significant ($p < 0.05$)
Grassland - Standing vs. Grassland - Seed Bank	~28	< 0.001	Yes
Woodland - Standing vs. Woodland - Seed Bank	~22	< 0.001	Yes
Bushland - Standing vs. Bushland - Seed Bank	~33	< 0.001	Yes
Bushland - Standing vs. Grassland - Seed Bank	~38	< 0.001	Yes
Bushland - Standing vs. Woodland - Seed Bank	~34	< 0.001	Yes
Woodland - Standing vs. Grassland - Seed Bank	~26	< 0.001	Yes
Grassland - Seed Bank vs. Woodland - Seed Bank	~4	> 0.05	No
Bushland - Seed Bank vs. Grassland - Seed Bank	~5	> 0.05	No
Bushland - Seed Bank vs. Woodland - Seed Bank	~2	> 0.05	No

DISCUSSION

The analysis of the Argo Forest's soil seed bank (SSB) reveals a complex ecological reservoir with significant implications for the ecosystem's resilience and restoration potential. Characterized by high species richness (62 species), the SSB composition exhibits a pronounced dominance of herbaceous life forms over woody species, a pattern consistent with findings in other seasonally dry tropical forests and woodlands (Dölle and Schmidt, 2009; Douh et al., 2018). This predominance highlights the established ecological principle that SSBs function as critical banks of viable, dormant propagules, buffering plant communities against threatening environmental stresses (Baskin and Baskin, 1998). The prevalence of herbaceous species can be attributed to a suite of adaptive traits aligned with disturbance-prone environments. Their short life cycles, high fecundity, and rapid reproductive turnover inherently predispose them to forming large, persistent seed banks (Klimešová et al., 2025). This adaptive strategy is profoundly influenced by seed morphology; herbs, grasses, and sedges typically produce smaller, more compact seeds compared to woody species. This diminutive size facilitates passive burial into deeper soil strata via abiotic processes like rain splash, thereby enhancing seed longevity by avoiding surface predation and buffering against temperature and moisture extremes (Maun, 1998; Fenner, 2017).

In stark contrast, the ecological strategy of many native woody species within this dry Afromontane system appears centered on different regeneration niches. Species within dominant genera like *Acacia* and *Combretum* often produce larger, nutrient-rich seeds adapted for immediate or rapid germination following dispersal, a trait favoring seedling establishment in competitive understory conditions or during brief favorable windows (Vandelook et al., 2008). This strategy typically results in the formation of transient or short-term persistent seed banks, where seeds either germinate quickly or lose viability within a single to a few seasons (Salazar et al., 2011). Consequently, their representation within the SSB is constrained. Additional limitations include slower reproductive cycles, higher susceptibility to vertebrate and insect predation due to larger seed size, and greater vulnerability to fungal pathogens in the soil, all factors that collectively diminish their seed bank density (Dalling et al., 2011; Tiebel et al., 2018).

This life-form contradiction drives the central finding of pronounced compositional dissimilarity between the SSB and the standing vegetation, a result corroborated by studies in analogous Ethiopian and East African ecosystems (Senbeta and Teketay, 2001; Mengistu et al., 2005). The low Sørensen similarity coefficient quantified this disconnect, indicating that the standing woody flora is poorly represented by dormant seeds in the soil. This disparity is not inconsistent but rather a predictable outcome of divergent regeneration strategies: a persistent seed bank dominated by herbaceous flora versus a standing vegetation structure dominated by woody species reliant on a transient seed bank or other regeneration mechanisms like resprouting (Chaideftou et al., 2009). Furthermore, the inherently low seed bank densities typical of dryland regions, exacerbated by the study area's drought-prone climate and sandy soils, further limit long-term seed survival and accumulation.

The observed exponential decline in viable seed density and species richness with increasing soil depth, with the majority of seeds (particularly woody species) confined to the upper 0–3 cm layer aligns with global meta-analyses. This vertical gradient reflects the interplay of dispersal mode, seed morphology, and burial processes. The confinement of larger woody seeds to superficial layers increases their exposure to predation and desiccation, while the deeper burial of smaller herbaceous seeds contributes to a persistent, though floristically distinct, reservoir (Thompson, 1996). The analysis across land-use types; Grassland, Woodland, Bushland, and Bare land demonstrated that spatial heterogeneity in disturbance regimes, microclimate, and biotic interactions significantly shapes SSB structure. The highest floristic similarity (Jaccard Index = 0.48) was observed between Grassland and Bushland, likely reflecting shared histories of intermediate disturbance and similar suites of pioneer and herbaceous species adapted to open-canopy conditions. Variations in species frequency among other land-use types can be attributed to differences in nutrient availability, light penetration (shade conditions), and the intensity and type of anthropogenic pressure, such as grazing and wood harvesting.

The synthesis of these findings yields critical, evidence-based implications for the conservation and restoration of the Argo Forest. Most significantly, the SSB, while rich in herbaceous diversity, constitutes an inadequate reservoir for the natural regeneration of the dominant standing woody flora following severe degradation or clearance. This severely limits the potential for passive natural regeneration to restore forest structure and composition. Therefore, predominant conservation policy must explicitly prioritize the direct protection and sustainable management of the existing standing forest as the primary strategy for maintaining biodiversity and ecosystem function.

For active restoration targeting the recovery of native woody species and forest structure, assisted interventions are essential. Direct seeding of native woody species may have limited success due to predation and edaphic constraints, making the planting of nursery-raised seedlings of target climax and endangered species a more reliable and effective technique (Shiferaw et al., 2018; Lin et al., 2022). Restoration frameworks must be coupled with integrated land management to address the abiotic and biotic barriers to seedling establishment. This includes controlling free-ranging livestock grazing, implementing measured erosion control measures on bare lands, and developing community-based fire management protocols to protect establishing saplings. In conclusion, while the soil seed bank of the Argo Forest features a capacity for ecosystem resilience through its persistent herbaceous component, it simultaneously highlights vulnerability in woody species regeneration. Effective stewardship, therefore, necessitates a dual approach; attentive protection of the standing forest matrix and the application of targeted, active restoration strategies informed by the clear limitations of the dormant seed reserve.

CONCLUSION AND RECOMMENDATIONS

Effective conservation and restoration of degraded ecosystems, particularly in fragile arid and semi-arid regions, requires a thorough understanding of soil seed banks, including their abundance, abundance quantity, diversity, and distribution. In the investigation of the soil seed bank of the Argo forest, 62 species from 48 genera and 29 families were recorded. Four families: Poaceae, Asteraceae, Fabaceae, and Solanaceae dominated the community and together accounted for 54% of all species. The results showed distinct spatial and structural patterns; herbaceous species had the highest density, whereas woody species exhibited very low seedling density. Moreover, bare land had the lowest species density, whereas grassland areas had the highest. With increasing soil depth, a predictable decrease in species richness was also noted. Crucially, the analysis revealed minimal correlation between the standing above-ground vegetation and the soil seed bank. When species are lost from the established flora, this suggests a limited ability for natural regeneration from the seed bank. Therefore, active interventions such as the establishment of nurseries for seedling production and plantation programs are highly recommended for the sustainable management and restoration of the region's priority indigenous species. A successful conservation strategy for the Argo Forest should address both direct threats and the ecosystem's limited natural recovery capacity.

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