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Original Article

### Soil Seed Bank Composition and Diversity in Areas Invaded with Invasive Alien Species in the Lower Montane Forest of Kilimanjaro National Park, Tanzania

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#### Keywords:

Montane Forest,  
Invasive alien Species,  
Soil Seedbanks,  
Mount Kilimanjaro,  
Restoration Ecology.

Knowledge of soil seed banks is crucial for the management of invasive alien species (IAS) and restoration planning of disturbed ecosystems. This study compared seed density and species composition of soil seed banks in areas invaded by IAS in the lower montane forest of Kilimanjaro National Park. Five sites were identified: four sites dominated by distinct invasive IAS, namely *Acacia mearnsii*, *Cupressus lusitanica*, *Eucalyptus* spp., and *Pinus patula*, and one site with natural forest. Soil samples were collected from ten plots (each 10 × 10 m) established in each vegetation site at three depth classes, making a total of 150 samples for the five sites. A seedling emergence method was employed to assess seed density, and species of emerged seedlings were identified. A total of 5,942 seeds belonging to 100 species, 82 genera, and 41 families germinated from the soil samples. The germinating seeds were composed of herbaceous plants, grasses, and a few woody species. The topsoil (1–5 cm) exhibited significantly higher seedling density than the litter fall and subsoil (6–10 cm) layers ( $F(2, 174) = 13.3$ ,  $p < .001$ ). The *P. patula* site exhibited the highest soil seed bank density (seedlings/m<sup>2</sup>) among all the sites studied, and the variation was statistically significant ( $F(4, 161) = 16.7$ ,  $p < 0.001$ ). The investigated sites exhibited a high number of undesirable seeds of invasive alien species such as *A. mearnsii*, *P. patula*, *Grevillea robusta*, and *Poa annua*. These findings highlight that the lower montane forest of Kilimanjaro National Park is rich in soil seed banks dominated by non-woody species and a few woody species. Therefore, forest restoration after the control of IAS may depend not only on the persistent soil seed bank but also on dispersal mechanisms from elsewhere and reforestation techniques.

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**INTRODUCTION**

The soil seed bank (SSB) is the natural storage of viable seeds and fruits in the soil, leaf litter, and humus, representing the past, present, and future plant community assemblages of the ecosystem (Teketay 2005; Gioria et al. 2012; Sileshi and Abraha 2014; Shiferaw et al. 2018). Soil seedbanks are classified on the basis of seed longevity into transient and persistent seed banks (Shen et al. 2007; Weerasinghe et al. 2019; Humphries and Florentine 2022). Transient Seedbank is a general term for all seeds that persist in the soil for a short duration, generally less than a year (Shen et al. 2007). These types of seeds germinate quickly or die if conditions are not favourable. On the other hand, persistent seedbank comprises seeds that remain viable in the soil for more than a year, often for several years or even decades (Gioria et al. 2021; Humphries and Florentine 2022). These seeds have an adaptation to remain dormant for extended periods. Therefore, soil seedbanks are vital for the ecological restoration of degraded ecosystems as they can easily germinate and grow once exposed to suitable conditions (Akomolafe et al. 2024). The storage of seeds in the soil (soil seed banks) remains one of the important adaptation mechanisms for most plant species from both natural and anthropogenic disturbances (Shiferaw et al. 2018). SSBs play an important role in serving as a repository for the production of subsequent

generations of plants to enable their survival (Sileshi and Abraha 2014; Chen et al. 2013). For example, Gioria et al. (2012) reported that the soil seedbank is a crucial adaptation mechanism for the survival and recruitment of invasive alien species.

Invasive Alien Species (IAS) are considered one of the primary threats to the conservation of native biodiversity worldwide (IPBES 2019; Roy et al. 2024). Most global invasive alien species are purposely introduced for various economic purposes (IPBES 2019). For example, according to Hulme et al. (2023), more than 37,000 alien species have been introduced due to ever-increasing human activities worldwide. Moreover, the interactions among these invasive species can further facilitate biological invasions (Hulme et al. 2023). These invasive alien species have serious and irreversible impacts on nature, undermining nature's capacity to contribute to people's livelihoods and affecting the quality of life (IPBES 2023).

Tanzania has about 554,500 hectares of forest plantations, the majority being composed of introduced species (URT 2015). Many introduced tree species may be transferred to natural ecosystems where they become invasive alien species (IPBES 2023). Mountain ecosystems are at higher risk of plant invasion due to climate warming and ever-increasing human land use, such as the intensification of human activities, human

population growth, and the expansion of tourism (Kueffer et al. 2013). Therefore, Hulme et al. (2023) emphasized that biological invasion can be facilitated by direct anthropogenic drivers, indirect drivers, and natural drivers. While direct drivers involve the role of human activities in the spread of invasive species, indirect drivers refer to demographic, economic, socio-cultural, and technological factors. On the other hand, natural drivers include events such as floods, storms, wildfires, and biodiversity loss (IPBES 2023).

The Mount Kilimanjaro landscape has experienced significant changes in forest cover and loss of biodiversity over the past decades due to both natural and anthropogenic disturbances (Lambrechts et al. 2002; William 2003; Misana et al. 2012; Kikoti et al. 2022). This famous mountain has been categorized according to eco-climatic vegetation zones into colline savanna (agriculture and pastures), sub-montane zone (coffee–banana plantations), montane zone (tropical rainy forest), subalpine zone (Erica shrub-lands), and alpine zone (Helichrysum vegetation zones) (Hemp 2006). The montane vegetation zone is further subdivided into lower, middle, and upper montane zones, with the lower montane forest bordering the inhabited submontane zone (Chagga home gardens). The lower montane forest is highly affected by both intentional and unintentional introduction of exotic species. TANAPA (2017) identified a total of 22 exotic species in the lower montane forest. Some species, such as *Acacia mearnsii*, *Eucalyptus* spp., *Cupressus lusitanica*, and *Pinus patula*, are among the 220 potential and invasive species recognized by the government of the United Republic of Tanzania (URT 2019).

The *A. mearnsii* De Wild. (Leguminosae) is native to Australia and highly invasive in most parts of the tropics (Seburanga 2015). Due to its invasiveness, this species is considered one of the world's top invasive trees in East Africa's Great Lakes region (Richardson and Rejmánek 2011; IUCN 2012). *P. patula* is a Central American closed cone pine that

is native and restricted to Mexico. This species was introduced in various parts of the world as a major plantation species (Nyoka 2003). However, among the *Pinus* genus, *P. patula* is the most aggressive invader of Afromontane forests in locations above 1,600 m a.s.l. Due to its ability to produce viable seeds, therefore listed as an invasive species (Nyoka 2003). The *Eucalyptus* species are native to Australia and widely planted worldwide (Nyoka 2003). *C. lusitanica* is a cypress that is native to Northern Central America and Mexico. However, due to its commercial value, this species was introduced to various parts of the world. It is reported as invasive in some regions, particularly Southern Africa (Nyoka 2003).

Many IAS are capable of forming persistent SSBs, which are an important determinant of their invasiveness (Gioria et al. 2021). Assessment of SSBs in areas with invasive species is highly relevant for identifying seeds of both invasive and native species stored in the soil (Gioria et al. 2012). This has practical applications in predicting the future spread of invasive alien species in the ecosystem (Gioria et al. 2021). The existence of persistent seed banks in the soil guarantees the availability of propagules that may germinate even in areas where invasive species have been controlled (Gioria et al. 2012; Humphries and Florentine 2022). SSBs are also highly relevant for planning ecosystem restoration; importantly, they are a good determinant of whether to opt for passive or active restoration (Akomolafe et al. 2024). Passive restoration is relevant when the native species richness in the SSB is high enough to enable natural succession to occur after the removal of the IAS (Weidlich et al. 2020). In a scenario where there is an inadequate SSB of desired tree species, active restoration involving planting trees remains the available option (Brancalion et al. 2017).

The invasiveness and expansion of IAS on Mount Kilimanjaro may be attributed to their characteristics and ability to form persistent soil seed banks. However, no study has been conducted

in the ecosystem to address the role of soil seed banks in the persistence and spread of invasive alien species and in the regeneration potential of native species. This study compared the floristic composition and species diversity of the germinable soil seed banks in areas invaded by different IAS (*A. mearnsii*, *Eucalyptus* spp., *C. lusitanica*, *P. patula*) and the adjacent natural forests. Two hypotheses were tested: 1) There are significant differences in the ability to form seedbanks between the studied invasive alien species. and 2) the seedling diversity of native species is higher in soils from the natural forest than in those from areas invaded by invasive species. Understanding the status of soil seed banks in areas infested with various IAS in the lower montane forest of KINAPA is vital for predicting the long-term impact of IAS on vegetation, developing strategies for IAS control, and

evaluating the restoration potential after the removal of IAS.

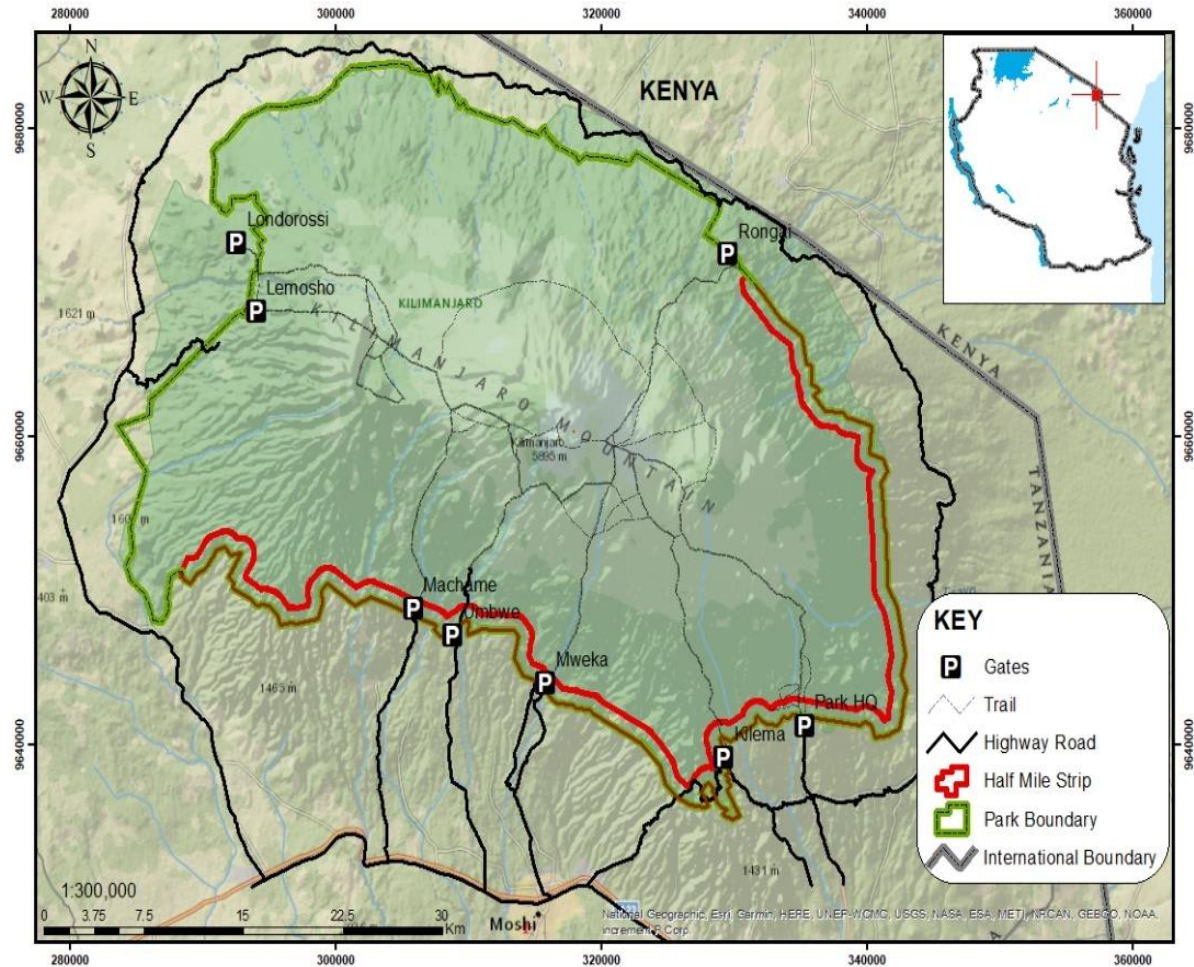
## MATERIALS AND METHODS

### Study Area Description

This study was conducted on the lower montane forest (Half Mile Strip) of KINAPA. Mount Kilimanjaro is the highest mountain in Africa and the world's largest free-standing mountain. The study area is located 330 kilometres south of the Equator, near the Kenya-Tanzanian border between latitude 2°50 – 3°10 S and longitude 37°10 – 37°40 E North of Tanzania (Figure 1). Kilimanjaro National Park (KINAPA) forms the upper part of the mountain from around 1800 m asl to the summit at 5895m asl with an area of 1,712 km<sup>2</sup>.

**Figure 1: Location of Kilimanjaro National Park, Showing the Lower Montane Forest (Half Mile Strip)**





The lower montane forest (Half Mile Strip) of Kilimanjaro National Park (KINAPA) roughly falls within the altitude range of 1800 m to 2200 m a.s.l. (Hemp 2006). The conservation of Mount Kilimanjaro began in 1921 when it was designated as a Forest Reserve by the German colonial government. In 1941, a section of the lower montane forest was demarcated as the "half-mile strip" to serve as a buffer zone between the montane forest and the inhabited submontane forests used for Chagga home gardens (William 2003). Local communities were permitted to engage in sustainable forest use within this buffer zone, including reforestation of degraded areas. However, some of the tree species used for reforestation were exotic (Kikoti 2022). In 1973, the upper part of Mount Kilimanjaro, starting at 2,700 meters above sea level, was upgraded to national park status, while the entire montane forest, including the half-

mile strip, remained under the management of the Forest and Beekeeping Division as a catchment forest (Lambrechts et al. 2001). Due to increasing anthropogenic pressures on the montane forest, the government in 2005 upgraded the entire forest, including the half-mile strip, to national park status (Kikoti 2022). However, parts of the lower montane forest, particularly on the eastern slopes in Rombo District, still contain remnants of exotic species (Kikoti 2022). These remnants lack proper silvicultural management, as TANAPA does not allow consumptive use of the forest and instead promotes passive restoration. The dominant exotic species in these areas include *Acacia mearnsii*, eucalyptus, *Cupressus lusitanica*, and *Pinus patula*, among others (TANAPA 2017).

### Study Design

A total of five sites were identified: four based on dominant IAS namely *A.mearnsii*, *C. lusitanica*, *Eucalyptus* spp., *P. patula*, and one site with natural forest in the lower montane forest of KINAPA. All sites were located on the eastern slopes of the mountain where abiotic conditions particularly climate and soils are similar. Soil samples were collected from ten plots (each sized 10 ×10 m) established in each vegetation site. Each plot was placed at an interval of 50 m from one another. In each of these plots, three (3) points were randomly selected for collection of soil samples. Soils were collected at three layers at different depths, namely: (i) litterfalls (0 cm), (ii) 1-5 cm depth class, and (iii) 6-10 cm depth class. The litterfall layer comprising organic debris and humus was included in the sampling process as it harbours a high density of seeds (Sileshi and Abraha 2014). A special flat shovel with 10 cm length and 10 cm width was used

when collecting soil samples as recommended by Luo et al. (2017). Then, the three samples taken from the same layer within a plot were mixed to form a soil composite to reduce intra-plot variability (Sileshi and Abraha 2014). This enabled the establishment of 30 soil samples in each vegetation site making a total of 150 samples for the five sites. The composite samples were kept in a cloth bag and transported to Kidia, KINAPA tree nursery project for germination experiments. Soil samples were spread as thinly as possible on wooden trays of the size 15 cm x 30 cm in a shade net and watered every day to allow germination (Plate 1). The seedlings from germinating seeds were identified, counted recorded, and uprooted every month from January 2021 to September 2021. Those seedlings that proved difficult to identify, were transplanted into polyethylene bags filled with a soil medium and left to grow until they lend themselves for identification.

**Plate 1: Germination Experiments at Kidia Tree Nursery Project**



### Data Analysis

A two-way analysis of variance (ANOVA) was conducted to examine the effects of vegetation site and soil vertical layer on SSB species richness, and

density, as well as the interaction between these factors. Before performing the ANOVA, the normality of the data was tested using the Shapiro-Wilk test, which is commonly used for smaller

sample sizes due to its high power in detecting deviations from normality. Additionally, Levene's test was employed to assess the homogeneity of variances, ensuring that the variance within each group was equal, a crucial assumption for ANOVA. Following the ANOVA, a post-hoc test was conducted to make pairwise comparisons between different sites and soil vertical layers. This analysis was performed using the open-source software Jamovi, version 2.3.28 (The Jamovi Project, 2022). The significance level for all statistical tests was set at 5%.

## RESULTS

### General Characteristics of Recorded Plant Species

A total of 5,942 seedlings representing 100 species, 81 genera, and 41 families germinated from the soil

**Table 1: General Characteristics of Plant Species Recorded in Soil Seed Bank from Sites with Various Invasive Species in the Lower Montane Forest**

Vegetation site	Species richness	Diversity (H')	Evenness index	Simpson Index
<i>A. mearnsii</i>	47	2.73	0.59	8.75
<i>C. lusitanica</i>	49	2.71	0.59	8.14
<i>Eucalyptus</i>	50	2.65	0.58	8.35
Natural Forest	50	3.24	0.70	18.14
<i>P. patula</i>	53	2.38	0.52	4.39

### Composition of Seedlings in the Lower Montane Forest

The soil seed banks of the lower montane forest of KINAPA were characterized by herbaceous lifeforms with 64 (64%) of all recorded seedlings, followed by graminoid with 16 species (16%), woody (14 species (14%) and fern (6 species (6%)) (Figure 2). The highest species richness of herbs was recorded in the *P. patula* site, followed by *C. lusitanica*, natural forest, *A. mearnsii* and *Eucalyptus* spp. (Figure 2). The dominant herbaceous families in descending order (percentage in brackets) were Asteraceae (47.5%),

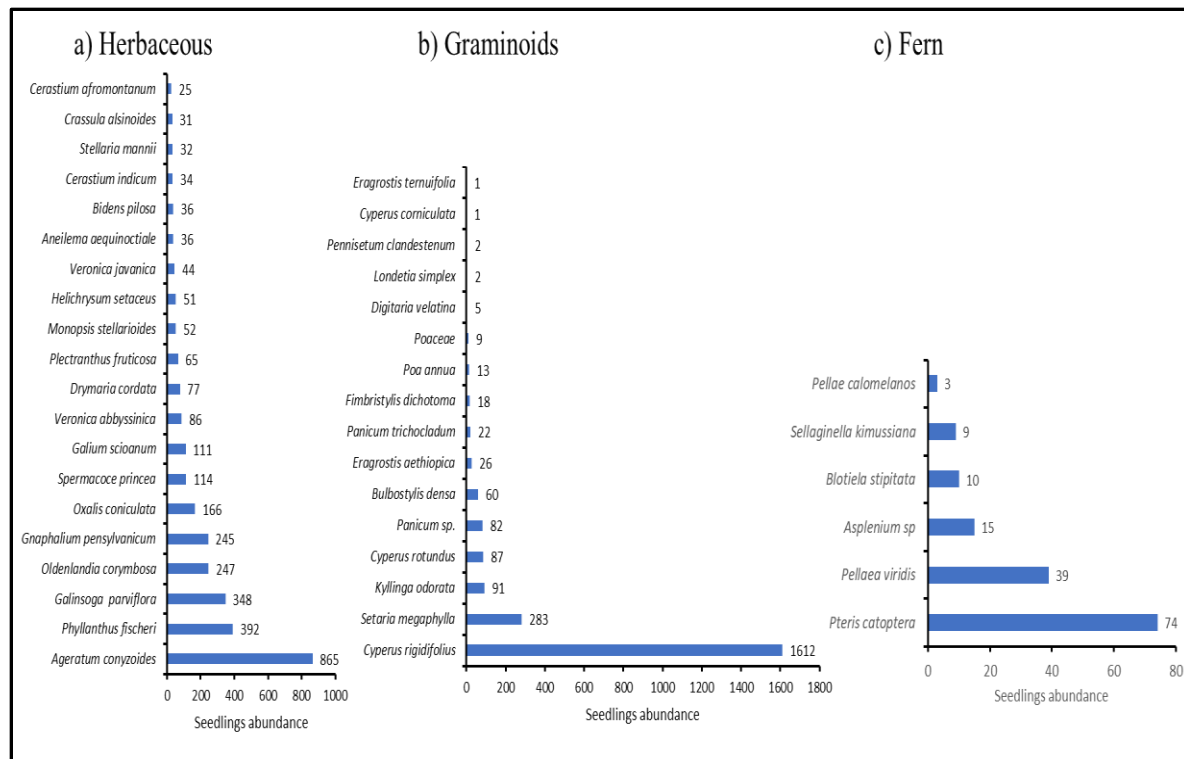
Rubiaceae (14.4%), Euphorbiaceae (12.1%) and Oxalidaceae (5.5%) among others. In all sites, herbaceous species were dominated by *Ageratum conyzoides* (26%), *Phyllanthus fischeri* (12%), and *Galinsoga parviflora* (10%) (Figure 2).

The highest plant diversity and evenness indices were observed in the soil seed bank of the natural forest, followed by areas infested with *A. mearnsii*, *C. lusitanica*, *Eucalyptus* spp., and *P. patula* (Table 1). However, in terms of plant species richness, the area invaded with *P. patula* scored the highest number, followed by the natural forest, *Eucalyptus* spp., *C. lusitanica*, and *A. mearnsii* (Table 1).

The graminoids were mostly dominated by grasses and sedges. Some of the highly recorded graminoids were *Cyperus rigidifolius*, *Setaria megaphylla*, *Kyllinga odorata*, and *Cyperus rotundus* among others (Figure 2). The dominant species in the fern lifeform were *Pteris catoptera* (49%), *Pellaea viridis* (26%), and *Asplenium* sp. among others (Figure 2).

**Figure 2: Composition of Seedlings Germinated from the Soil Seed Bank in the Lower Montane Forest of Kilimanjaro National Park**





### Composition of Woody Seedlings in the Lower Montane Forest

A total of 14 woody species germinated from the soil seed bank, with 4 species (28%) being exotic and 10 species (71.4%) being indigenous trees (Tables 2). The highest number of woody species were recorded in the *Eucalyptus* spp. site, followed by *C. lusitanica*, natural forest, *A. mearnsii*, and *P. patula* sites, with 8, 6, 5, 4, and 3 species, respectively (Tables 2). In descending order, the highest seedling densities (individuals/m<sup>2</sup>) were dominated by *Acacia mearnsii*, *Croton macrostachyus*, *Macaranga kilimandscharica*,

*Grevillea robusta*, and *Syzygium guineense* (Table 2).

Apart from the native seedlings, exotic seedlings (IAS) were recorded in the soils from the *A. mearnsii*, *Eucalyptus* spp., *C. lusitanica*, and *P. patula* sites (2 species in each site). However, there were no IAS seedlings recorded in the natural forest soils. The most dominant IAS woody species was *Acacia mearnsii* (59%), recorded in areas invaded by *A. mearnsii*, *Eucalyptus*, and *C. lusitanica*. This was followed by *Grevillea robusta* (5%), and *P. patula* and *Acacia longifolia*, each with 1% (Table 2).

**Table 2: Soil Seed Bank Density (seedlings / m<sup>2</sup>) of Woody Species among Sites with Various Invasive Alien Species in the Lower Montane Forest of Mount Kilimanjaro**

SN	Plant species	Density (Seedlings / m <sup>2</sup> )					Total	RD (%)	Remarks
		A	C	E	N	P			
1	<i>Acacia mearnsii</i>	2800	1,400	2900	-	-	7,100	59	IAS
2	<i>Croton macrostachyus</i>	-	200	200	-	700	1,100	9	Native
3	<i>Macaranga kilimandscharica</i>	500	-	400	100	-	1,000	8	Native
4	<i>Grevillea robusta</i>	100	400	-	-	100	600	5	IAS
5	<i>Syzygium guineense</i>	-	300	-	300	-	600	5	Native



6	<i>Toddalia asiatica</i>	200	-	100	-	100	400	3	Native
7	<i>Cissus integrifolia</i>	100	-	200	-	-	300	2	Native
8	<i>Sparrmania ricinocarpa</i>	-	-	300	-	-	300	2	Native
9	<i>Capparis tomentosa</i>	-	200	-	-	-	200	2	Native
10	<i>Acacia longifolia</i>	-	-	100	-	-	100	1	IAS
11	<i>Dodonaea viscosa</i>	-	100	-	-	-	100	1	Native
12	<i>Euphorbia prostrata</i>	-	-	100	-	-	100	1	Native
13	<i>Olea europaea ssp. africana</i>	-	-	-	100	-	100	1	Native
14	<i>Pinus patula</i>	-	-	-	-	100	100	1	IAS
<b>Total</b>		<b>3,700</b>	<b>2,600</b>	<b>4,300</b>	<b>500</b>	<b>1,000</b>	<b>12,100</b>	<b>100</b>	

\*A= *Acacia mearnsii*, C= *Cupressus lusitanica*, E = *Eucalyptus* spp., N = Natural Forest and P = *Pinus patula*, RD = Relative density, IAS = Invasive alien species

### Composition of Seedlings Along the Vertical Soil Layers

#### Litter Fall and Humus Layer

Litter fall and humus layer of the lower montane forest was among the layers rich in soil seed banks. A total of 75 seedling species germinated from the litterfall layer of the study area. The dominant seedlings in terms of relative density came from the following plant species: *Ageratum conyzoides* (18%), *Cyperus rigidifolius* (18%), *Galinsoga parviflora* (6%), *Gnaphalium pensylvanicum* (5%), *Phyllanthus fischeri* (5%), *Oldenlandia corymbosa* (4%), *Setaria megaphylla* (4%), *Oxalis coniculata* (3%), *Spermacoce princea* (3%), and *Drymaria cordata* (2%).

This soil layer was also rich in woody seedlings, including *Acacia mearnsii* (3%), *Croton macrostachyus* (0.3%), *Grevillea robusta* (0.2%), *Cissus integrifolia* (0.1%), *Toddalia asiatica* (0.1%), *Acacia longifolia* (0.1%), *Macaranga kilimandscharica* (0.1%), *Macaranga kilimandscharica* (0.1%) and *Syzygium guineense* (0.1%).

#### Composition of Seedlings in the 1 – 5 cm Depth Class

The highest species richness of SSB seedlings was recorded in the 1–5 cm soil layer, with a total of 80 species. These seedlings comprised *Cyperus rigidifolius* (31%), *Ageratum conyzoides* (14%),

*Phyllanthus fischeri* (6%), *Galinsoga parviflora* (6%), *Oldenlandia corymbosa* (5%), *Setaria megaphylla* (4%), *Gnaphalium pensylvanicum* (4%), *Galium scioanum* (2%), *Oxalis coniculata* (2%), *Pteris catoptera* (2%) and *Kyllinga odorata* (2%) and *Pellaea viridis* (1%). In this depth class, a total of 8 woody species were recorded, including *Acacia mearnsii* (1%), *Syzygium guineense* (0.2%), *Croton macrostachyus* (0.2%), *Macaranga kilimandscharica* (0.2%), *Grevillea robusta* (0.1%), *Sparrmania ricinocarpa* (0.1%), *Toddalia asiatica* (0.04%), and *Cissus integrifolia* (0.04%).

#### Composition of Seedlings in the 6 – 10 cm Depth Class

A total of 61 seedling species germinated from the subsoil (6–10 cm) depth class. The dominant seedlings in terms of relative density came from the following plant species: *Cyperus rigidifolius* (29%), *Ageratum conyzoides* (13%), *Phyllanthus fischeri* (9%), *Setaria megaphylla* (7%), *Galinsoga parviflora* (6%), *Gnaphalium pensylvanicum* (4%), *Oxalis coniculata* (3%), *Oldenlandia corymbosa* (3%) and *Cyperus rotundus* (2%). Likewise, woody seedlings of *Acacia mearnsii* (0.4%), *Macaranga kilimandscharica* (0.2%), *Croton macrostachyus* (0.1%), *Dodonaea viscosa* (0.1%), *Euphorbia prostrata* (0.1%), *Capparis tomentosa* (0.1%) and *Grevillea robusta* (0.1%) germinated, though in small proportions as shown in the brackets.

#### Seedling Species Richness

Species richness was assessed across all lifeforms: woody, herbaceous, and graminoid species (Figure 3). The *P. patula* site exhibited the highest overall plant species richness ( $10.5 \pm 0.7$ ), followed by *C. lusitanica* ( $8.53 \pm 0.7$ ), *Eucalyptus* spp. ( $7.3 \pm 0.7$ ), natural forest ( $7.14 \pm 0.7$ ), and *A. mearnsii* ( $6.79 \pm$

0.6) (Figure 3). The differences in species richness between *P. patula* and the other vegetation types (*A. mearnsii*, *C. lusitanica*, *Eucalyptus* spp., and natural forest) were statistically significant ( $p < 0.05$ ) (Table 3; Table 4).

**Table 3: Results of two-way ANOVA Indicating the Interaction between Vegetation Site and Soil Vertical Layers in the Lower Montane Forest of Kilimanjaro National Park**

	Sum of Squares	df	Mean Square	F	p	$\eta^2p$
Site	37.35	4	9.337	6.592	< .001	0.183
Soil_layer	18.4	2	9.199	6.495	0.002	0.099
Site * Soil_layer	2.67	8	0.334	0.236	0.983	0.016
Residuals	167.14	118	1.416			

**Table 4: Post-hoc Analysis of Species Richness of SSB among Sites with Different Invasive Alien Species in the Lower Montane Forest**

Comparison		MD	SE	df	t	p	Cohen's d
Site	Site						
<i>A. mearnsii</i>	<i>C. lusitanica</i>	-1.65	0.98	154	-1.69	0.09	-0.42
	Eucalypts	-0.36	0.95	154	-0.38	0.70	-0.09
	<i>P. patula</i>	-3.64	0.98	154	-3.71	< .001	-0.92
	Nat. forest	-0.27	0.96	154	-0.28	0.78	-0.07
<i>C. lusitanica</i>	Eucalypts	1.29	0.96	154	1.35	0.18	0.33
	<i>P. patula</i>	-1.98	0.99	154	-2.01	0.05	-0.50
	Nat. forest	1.39	0.97	154	1.44	0.15	0.35
Eucalypts	<i>P. patula</i>	-3.27	0.96	154	-3.43	< .001	-0.83
	Nat. forest	0.09	0.93	154	0.10	0.92	0.02
<b>P. patula</b>	Nat. forest	3.37	0.97	154	3.49	< .001	0.85

Note. Comparisons are based on estimated marginal means.

For woody species, the highest species richness was recorded at the *Eucalyptus* spp. site ( $1.38 \pm 0.2$ ), followed by *A. mearnsii* ( $1.21 \pm 0.1$ ), *C. lusitanica* ( $1.06 \pm 0.1$ ), and both *P. patula* and the natural forest (1.0) (Table 2, Figure 3). For herbaceous species, *P. patula* ranked highest with a species richness of  $7.29 \pm 0.6$ , followed by *C. lusitanica* ( $5.84 \pm 0.5$ ), natural forest ( $5.49 \pm 0.5$ ), *Eucalyptus* spp. ( $4.78 \pm 0.5$ ), and *A. mearnsii* ( $4.31 \pm 0.4$ ). Additionally, *P. patula* had the highest species richness of graminoids ( $3.29 \pm 0.3$ ), while the

lowest richness was recorded in the natural forest ( $1.63 \pm 0.2$ ) (Figure 3).

In terms of vertical distribution, the highest species richness was observed in the 1-5 cm soil layer (topsoil), with  $9.45 \pm 0.63$ , followed by litterfall ( $7.34 \pm 0.5$ ) and subsoil ( $7.18 \pm 0.5$ ) (Figure 3). Post-hoc analysis revealed that the species richness in the topsoil was significantly higher than in litterfall and subsoil (Table 3; Table 5).

**Table 5: Post-hoc Analysis of Species Richness of Soil Seedbank Across the Vertical Soil Layers in the Lower Montane Forest of Kilimanjaro National Park**

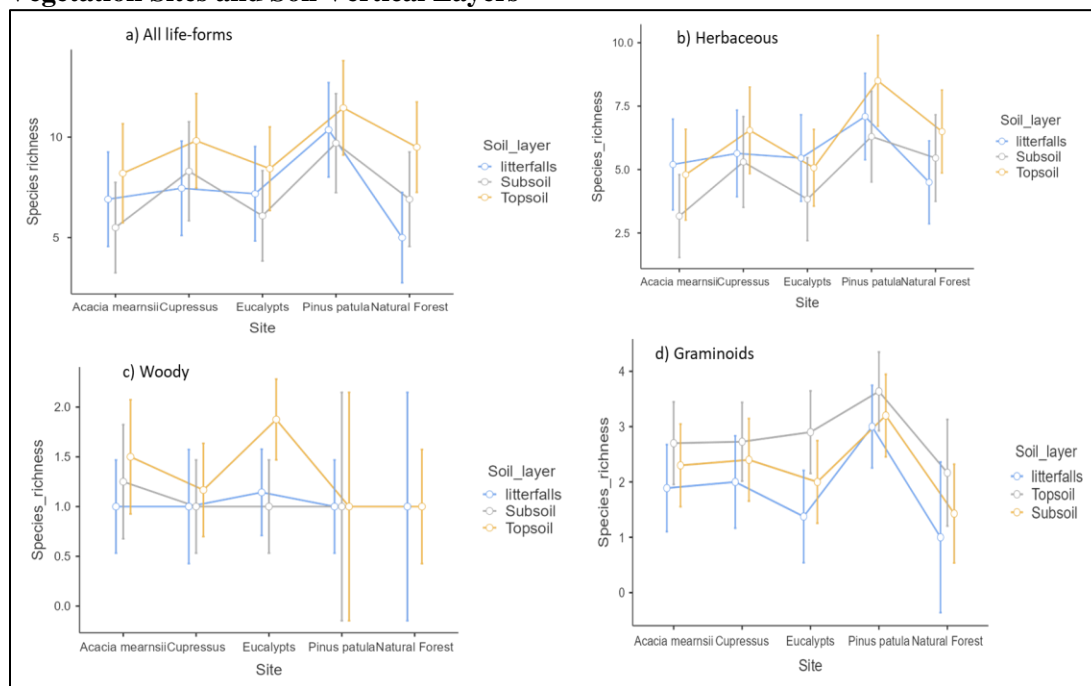
Comparison
------------

		Mean		df	t	p	Cohen's d
Soil_layer	Soil_layer	Difference	SE				
litterfalls	Subsoil	0.0833	0.75	154	0.111	0.912	0.0211
	Topsoil	-2.0984	0.741	154	-2.83	0.005	-0.5321
Subsoil	Topsoil	-2.1818	0.746	154	-2.925	0.004	-0.5532

Note. Comparisons are based on estimated marginal means.

For woody species, the topsoil had the highest species richness ( $1.43 \pm 0.1$ ), followed by subsoil ( $1.06 \pm 0.1$ ) and litter fall ( $1.04 \pm 0.04$ ). In terms of herbaceous species, the topsoil also ranked highest ( $6.21 \pm 0.4$ ), followed by litter fall ( $5.56 \pm 0.4$ ) and subsoil ( $4.73 \pm 0.4$ ). For graminoids, the topsoil again exhibited the highest species richness ( $2.32 \pm 0.2$ ), followed by subsoil and litter fall (Figure 3).

**Figure 3: Mean species Richness for All Life Forms, Herbaceous, Woody, and Graminoid Across Vegetation Sites and Soil Vertical Layers**



The two-way ANOVA revealed that the main effects i.e. vegetation site and vertical soil layers were statistically significant ( $p < 0.05$ ) (Table 3). However, the interaction of effect between the two variables was not statistically significant ( $p < 0.05$ ) (Table 3). Further post-hoc analyses were done to identify specific means that were statistically significant (Table 4, 5). The species richness of *A. mearnsii* litter fall was significantly lower than that of *P. patula* litter fall ( $p = 0.042$ ) and *P. patula* topsoil ( $p = 0.008$ ). Additionally, *A. mearnsii* subsoil richness was significantly lower than that of *C. lusitanica* topsoil ( $p = 0.010$ ), natural forest

topsoil ( $p = 0.014$ ), and *P. patula* litterfall ( $p = 0.003$ ). The variation between *P. patula* litterfall and *P. patula* topsoil was also statistically significant ( $p < 0.05$ ). The *Eucalyptus* spp. litterfall richness was significantly lower than that of *P. patula* topsoil ( $p = 0.012$ ). Other post-hoc analyses indicated that *Eucalyptus* spp. subsoil richness was significantly lower than that of natural forest topsoil ( $p = 0.035$ ), *P. patula* litterfall ( $p = 0.010$ ), *P. patula* subsoil ( $p = 0.034$ ), and *P. patula* topsoil ( $p = 0.001$ ). Similarly, natural forest litterfall richness was significantly lower than natural forest topsoil ( $p$

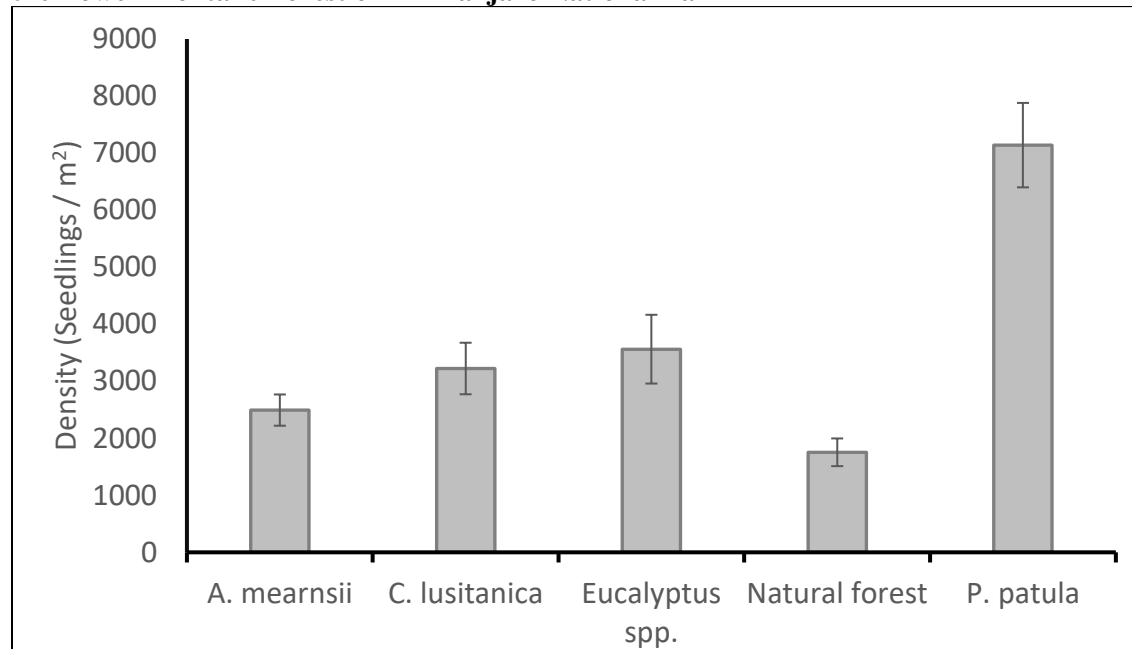
= 0.006), *P. patula* litterfall ( $p = 0.002$ ), *P. patula* subsoil, and *P. patula* topsoil ( $p < 0.05$ ).

#### Density of Soil Seed Bank in the Lower Montane Forest of Kilimanjaro National Park

The mean seedling density of SSB from the lower montane forest of KINAPA varied considerably among the five study sites (four sites with IAS and one natural forest site). The highest density was recorded in the *P. patula* site ( $7,139 \pm 740$

seedlings/m<sup>2</sup>), followed by *Eucalyptus* spp., *C. lusitanica*, *A. mearnsii*, and natural forest (Figure 4). There was a significant difference in mean seedling density across the five study sites,  $F(4, 161) = 16.7$ ,  $p < 0.001$ ). Post hoc comparison using Tukey's HSD revealed that the mean seedling density for *P. patula* was significantly higher than for *Eucalyptus* spp., *C. lusitanica*, *A. mearnsii*, and natural forest.

**Figure 4: Density of Seedlings (Individuals/m<sup>2</sup>) among Areas with Various Invasive Alien Species in the Lower Montane Forest of Kilimanjaro National Park**



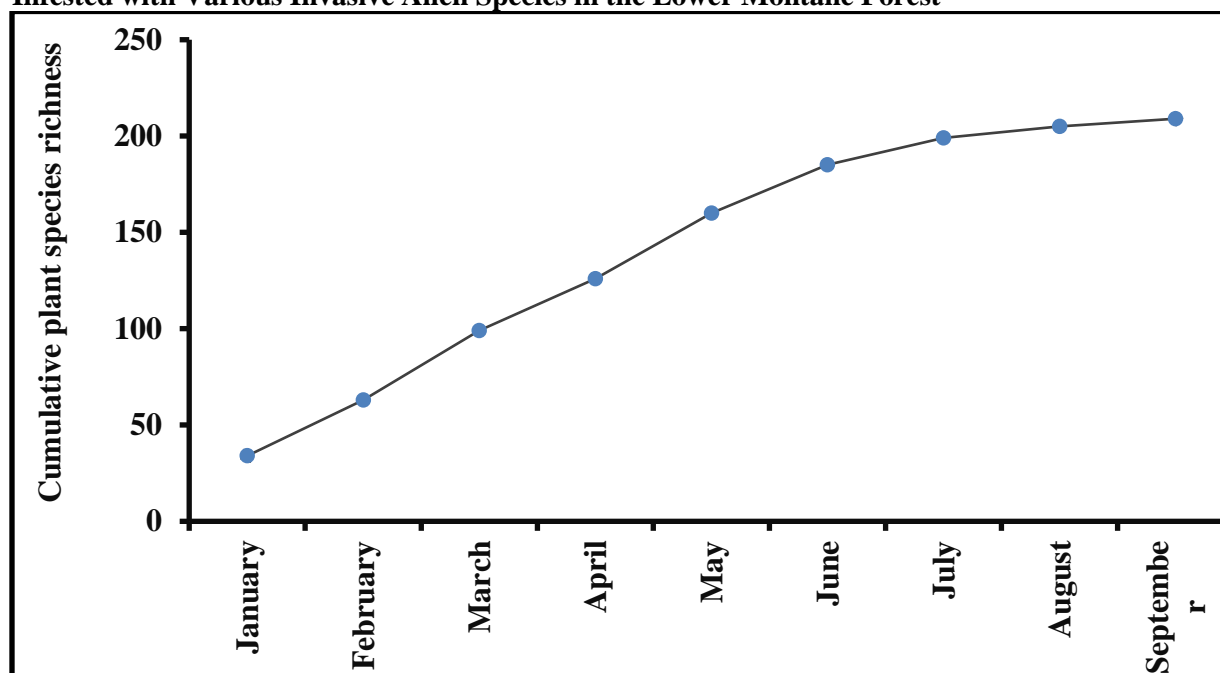
The vertical distribution of the soil seed bank indicated that the topsoil (1–5 cm) had the highest density of soil seed banks (SSB), with  $5063 \pm 560$  seedlings/m<sup>2</sup>. This was followed by the subsoil (6–10 cm) and litterfall layers, with densities of  $3207 \pm 375$  and  $2107 \pm 297$  seedlings/m<sup>2</sup>, respectively. Analysis of variance revealed a significant difference in seed bank density (seedlings/m<sup>2</sup>) among the three soil depth classes,  $F(2, 174) = 13.3$ ,  $p < .001$ . The post hoc ANOVA test based on the Tukey-Kramer test showed a significantly higher soil seed bank density (seedlings/m<sup>2</sup>) in the topsoil (1–5 cm) than in the litterfall layer ( $t$ -value = 2.75,  $df = 93.1$ ,  $p$ -value = 0.019) and subsoil (6–10 cm)

( $t$ -value = 2.75,  $df = 93$ ,  $p$ -value = 0.019). Other pairs, soil depth class 6–10 cm and litterfall, were not statistically significant ( $t = 2.3$ ,  $df = 109.8$ ,  $p = 0.06$ ).

#### Cumulative Plant Species Richness

Cumulatively, a total of 209 plant species germinated from the soil seed bank experiment in the lower montane forest of KINAPA (Figure 5). It was observed that from January 2021 to June 2021, there was a rapid increase in the number of emerging seedlings. However, from July to September, there was a decreasing trend in seedling emergence from the soil (Figure 5).



**Figure 5: The Cumulative Richness of Plant Species Recorded in the Above Soil Layer from Sites Infested with Various Invasive Alien Species in the Lower Montane Forest**

## DISCUSSION

### Composition of Soil Seed Bank in the Lower Montane Forest

The findings from this study indicate that the soils of the lower montane forest of Kilimanjaro National Park are rich in soil seed banks. However, the majority of seed banks were dominated by herbaceous and graminoid species with few woody species (Table 1 & 2), suggesting that the regeneration of natural forests may be slow. The dominance of herbaceous seeds in the lower montane forest KINAPA can be attributed to several characteristics, such as the ability of these plants to produce large quantities of light and small-sized persistent seeds that are easily dispersed by wind and water (Sera & Sery, 2004). This finding is consistent with previous research that has reported a dominance of herbaceous seeds in the soil seed bank of other Afromontane forests (Lemenih and Teketay 2006; Mukhongo et al. 2011; Ayele 2014; Kassa et al. 2019). For instance, Ayele (2014) recorded a high proportion of herbaceous species accounting for 65.7% of Ethiopian Afromontane forests. Similar findings were also observed in the

W Park Transboundary Biosphere Reserve, West Africa, where all soil samples were dominated by herbaceous species (Savadogo et al. 2016).

In tropical forest ecosystems, the dominance of herbaceous species in disturbed areas plays a crucial role in forest development. Lebrija-Trejos (2009) noted that secondary forest succession in the tropics typically begins with the dominance of herbs and shrubs, followed by short-lived pioneers, long-lived pioneers, and ultimately shade-tolerant species resembling mature forests. This progression from herbaceous and shrubby pioneers is seen as a significant stage in forest recovery, as observed in the Engushai area within Kilimanjaro National Park (Kikoti et al. 2022).

The limited representation of woody species in the soil seed bank of the lower montane forest (Table 2) may be attributed to anthropogenic disturbances and the prevalence of invasive alien species dominating the above-ground vegetation (Kikoti 2022). Surprisingly, natural forests with a high diversity of indigenous woody species showed lower germination rates of woody seedlings compared to

areas invaded by IAS (Table 2). This discrepancy can be explained by the characteristics of tropical montane forest seeds, which are often desiccation-sensitive or recalcitrant, meaning they germinate quickly after dispersal with a short period of viability (Ferrandis et al. 2011; Ayela 2014). Ayela (2014) similarly linked the lower representation of woody seedlings in Ethiopian Afromontane Forest soil seed banks to the short lifespan of these seeds compared to herbaceous seeds. Additionally, seeds of woody species may be vulnerable to infection by pathogens or predation by mammals, factors that could affect their germination success in the lower montane forest of KINAPA (Ayela 2014). Furthermore, the emergence of seeds from the soil seed bank may also be influenced by factors such as seed dormancy, which can prevent germination during the assessment period (Bewley and Black 1994). This limitation is recognized in the seed emergence method used to assess soil seed banks (Savadogo et al. 2016). Mukhongo et al. (2011) linked the low representation of woody seedlings in Kakamega Forest, Western Kenya, to the dense canopy cover of indigenous trees, which restricts light penetration to the forest floor.

The germination of woody species from the soil seed bank in the lower montane forest of KINAPA appears to be relatively higher compared to some other Afromontane forest ecosystems. For instance, Sileshi and Abraha (2014) found only two woody species in the soil seed banks of the Hgumbirda National Forest Priority Area, Ethiopia, using a similar seedling emergence method. Similarly, Assefa (2011) recovered only five woody species from the soil seed banks of Abay Millennium Park, indicating lower diversity compared to KINAPA. Several factors may contribute to the relatively higher germination of woody species observed in KINAPA. The proximity of Kidia Tree Nursery, where the experiments were conducted, to the lower montane forest likely provided suitable environmental conditions for seed germination. Additionally, the longer duration of the experiment (9 months) compared to previous studies (e.g., 5

months by Sileshi and Abraha 2014) may have allowed more time for seeds to germinate.

The presence of high densities of seeds from species like *A. mearnsii*, *P. patula*, *Grevillea robusta*, and *A. longifolia* in the soil seed banks of KINAPA (Table 2) suggests these species have the potential to become sources of future invasion into both natural forests and areas where invasive alien species (IAS) have been controlled. *A. mearnsii*, in particular, exhibited high seed bank densities in sites invaded by *Eucalyptus* spp. (2,900 seedlings / m<sup>2</sup>), *A. mearnsii* (2,800 seedlings/m<sup>2</sup>), and *C. lusitanica* (1,400 seedlings/m<sup>2</sup>) (Table 2), indicating their capacity to form long-lived dormant soil seed banks. Similar findings on the persistence and potential for invasion of *A. mearnsii* seeds have been reported in South Africa (Goets et al. 2018) and other Afromontane ecosystems (Sileshi and Abraha 2014; Kassa et al. 2019; Akomolafe et al. 2022).

The dominance of IAS such as *A. mearnsii*, *P. patula*, *C. lusitanica*, and *Eucalyptus* spp. in above-ground vegetation can suppress indigenous trees, thereby reducing the availability of native seeds for natural regeneration. These IAS may also release allelopathic chemicals that affect soil properties and seed banks, further hindering natural regeneration processes. Consequently, seeds dispersed by animals (zoochory), gravity (ballistochory), wind (anemochory), and water (hydrochory) from remaining native forests may be critical for sustaining natural regeneration in such areas (Chapman et al. 2016). Many trees in tropical forests produce fleshy fruits adapted for dispersal by animals like bats, birds, and primates, reinforcing the importance of intact native forests as seed sources for the restoration of degraded areas.

### **Distribution of Soil Seed Bank in the Soil Layers**

The topsoils (1-5 cm) in the lower montane forest of KINAPA exhibited the highest density of soil seed banks compared to litterfall and subsoils, indicating their readiness for germination under favourable

conditions. The primary factor contributing to the prevalence of seeds in the topsoil layer is their longevity in the soil. The process of soil burial can be slow, and many seeds either lose viability or are lost in the deeper soil layers. Subsoils typically contain lower densities of soil seed banks due to soil compaction, which restricts the vertical penetration of seeds (Toth et al. 2022). During their movement through the soil, short-lived seeds often fail to reach the deeper layers and lose viability (Bekker et al. 1998). This loss of viability is further exacerbated by unfavourable conditions in the subsoils, such as lower oxygen levels and increased decay. Bekker et al. (1998) also reported that the vertical movement of seeds in subsoils is determined by factors such as seed mass and seed shape. The observed decline in soil seed bank density from topsoil (1-5 cm) to subsoils (6-10 cm) in KINAPA is consistent with findings from other studies where seed density decreases with increasing soil depth (Mukhongo et al. 2011; Ayele 2014; Sileshi and Abraha 2014; Savadogo et al. 2016).

In the lower montane forest of KINAPA, invasive alien species like *A. mearnsii* and *G. robusta* have been found persistently across all soil depth classes (litterfall, 1-5 cm, and 6-10 cm), indicating their potential for future regeneration. *A. mearnsii*, in particular, stands out as the most abundant woody seedling in the soil seed bank. This species is known for its vigorous growth, nitrogen-fixing capabilities, and prolific seed production. Its seeds are highly persistent in the soil, remaining viable for extended periods (Roja-Sandoval and Pasiecznik 2015; Seburanga 2015; Goets et al. 2018). *A. mearnsii* seeds are dispersed through various mechanisms such as water, mammals, and birds (Roja-Sandoval & Pasiecznik, 2015; Seburanga, 2015). Similarly, *G. robusta* is noted for its successful invasion due to early and abundant seed production, small size and papery wings that facilitate long dispersion by winds (Roja-Sandoval 2015). The presence of *G. robusta* seeds in the soil seed bank of KINAPA may have originated from nearby Chagga agroforestry systems on the slopes of Mount Kilimanjaro. These

systems could serve as sources of seeds due to their proximity and potential for seed dispersal into adjacent natural habitats.

The presence of woody species such as *Macaranga kilimandscharica*, *Croton macrostachyus*, and *Dodonaea viscosa* germinating across all three soil layers suggests their potential suitability for ecological restoration efforts in degraded ecosystems. *Macaranga kilimandscharica* is known as a fast-growing pioneer species in Afromontane forests, characterized by its ability to produce numerous small seeds (Kleinschroth et al. 2013; Kikoti 2022). This adaptation allows it to establish itself quickly under favourable conditions. *Croton macrostachyus*, belonging to the Euphorbiaceae family, serves as a deciduous pioneer tree particularly on degraded mountain slopes between 1300 to 2500 meters above sea level (Legesse 2021). It produces viable seeds that germinate when conditions of fertility, moisture, and aeration are optimal. However, its seeds may lose viability relatively quickly in hot environments (Legesse 2021). *Dodonaea viscosa*, a pioneer species in the Sapindaceae family, produces numerous seeds with water-impermeable coats, causing physical dormancy (Jaganathan and Liu 2014). These seeds are tolerant of desiccation and can maintain viability for long periods, particularly after disturbances like fire or soil disruption (Kikoti 2022). Seasonal changes in temperature and rainfall help break dormancy, promoting germination (Jaganathan and Liu 2014).

The presence of these woody species in all soil layers, including subsoils (6-10 cm), holds significant ecological implications for the passive restoration of the lower montane forest of Mount Kilimanjaro. Research by Maskova and Poschlod (2023) found that deeper burial depths can enhance seed persistence, contributing to longer-term viability. Subsoils, therefore, serve as crucial repositories for subsequent generations of plants, ensuring their survival and establishment, particularly after disturbances (Sileshi and Abraha

2014). Seed persistence in subsoil layers is influenced by specific germination traits such as dormancy mechanisms, light requirements, and temperature conditions (Maskova and Poschlod 2023).

Water berry (*Syzygium guineense*) is a shade-tolerant species that germinated exclusively in the litter fall and 1-5 cm depth classes of the soil seed bank in the lower montane forest of KINAPA. This tree species produces recalcitrant seeds, which means they have a short period of viability under favourable environmental conditions (Legesse 2021). Recalcitrant seeds are typically unable to tolerate drying and have limited storage potential compared to orthodox seeds (seeds that can tolerate desiccation and have longer storage life) (Ferrandis et al. 2011). The absence of *S. guineense* in the subsoils (6-10 cm depth class) of the lower montane forest of KINAPA may be attributed to several factors. Firstly, the species may have difficulty penetrating deeper soil layers due to the size of its seeds, which can affect their burial and germination potential in deeper soil depths (Bekker et al. 1998). Secondly, the short viability period of its seeds limits their persistence in the soil over extended periods. These characteristics make the litter fall and shallow soil layers more conducive for the germination and establishment of *S. guineense*. Gross-Camp (2009) identified *S. guineense* as one of the large-seeded tropical montane trees, with seed sizes recorded at 13 mm in Nyungwe National Park. This large seed size can influence the dispersal mechanisms and ecological niche of the species, affecting its distribution and persistence in different soil environments, including the soil seed bank.

### Variation of Soil Seed Bank among IAS

The soil seed banks from the *P. patula* site had the highest SSB density (seedlings/m<sup>2</sup>) among all the sites studied, and this variation was statistically significant. This higher density and richness of soil seed banks associated with invasive alien species (IAS) such as *Eucalyptus*, *C. lusitanica*, and *A. mearnsii* compared to the natural forest can be

attributed to several factors. Disturbed tropical forests often have abundant soil seed banks due to early-successional species, which produce many small seeds that form persistent seed banks (Vazquez-Yanes and Orozco-Segovia 1993). These seeds remain viable for long periods and play a key role in forest regeneration, allowing rapid colonization and recovery after disturbances like logging or fire (Humphries and Florentine 2022). These seed banks are essential for promoting succession and resilience in tropical ecosystems (Kikoti et al. 2022). Moreover, seeds from the natural forest can disperse into areas with invasive species through various mechanisms such as water, animals, and wind (Chapman et al. 2016). This influx of seeds can contribute significantly to the regeneration and diversity of plant species in these areas. Studies, such as those by Becerra and Montenegro (2013), have indicated that plantations of species like *P. radiata* do not necessarily inhibit or delay the recolonization of native species during secondary succession. In fact, invasive alien species have been observed in various contexts to facilitate the establishment and growth of native species, as noted in research by Lindsay and French (2005); Dewine and Cooper (2008) and Becerra and Montenegro (2013).

### Conservation Implication

This study used the seedling emergence method, which is effective for detecting viable seeds; however, it may underestimate the total seed bank, as dormant seeds that require specific germination cues (e.g., fire, stratification) might not have emerged under the controlled conditions. Nevertheless, the findings from this study contribute to ecological theory by demonstrating how invasive species alter the composition and density of soil seed banks, favouring the persistence of undesirable species and potentially inhibiting natural regeneration. Therefore, knowledge of the composition, density, and viability of seeds within these soil seed banks can inform management strategies aimed at controlling IAS, restoring native



vegetation, and preventing further ecological degradation. For example, the high density of *Acacia mearnsii* seeds in the soil seed bank represents a key adaptation contributing to its invasiveness in the lower montane forest of Kilimanjaro National Park. Hence, understanding seed persistence is essential for predicting plant invasiveness and identifying potentially invasive plants before their introduction (Gioria et al., 2021).

The findings from this study provide a detailed understanding of the condition of soil seed banks in areas infested with invasive alien species (IAS). This knowledge is crucial for predicting the potential for future recruitment of invasive plants, understanding their ability to spread and establish in new environments, and assessing their long-term persistence in the ecosystem. Therefore, the knowledge of the composition, density, and viability of seeds within these soil seed banks, may inform management strategies aimed at controlling IAS, restoring native vegetation, and preventing further ecological degradation. For example, the high density of *Acacia mearnsii* seeds in the soil seed bank is a key adaptation contributing to its invasiveness in the lower montane forest of Kilimanjaro National Park. Hence, understanding seed persistence is essential for predicting plant invasiveness and identifying potentially invasive plants before their introduction (Gioria et al. 2021).

The germination of invasive species such as *Acacia mearnsii*, *Acacia longifolia*, *Pinus patula*, and *Grevillea robusta* from soil seed banks necessitates strategic control measures. Therefore, experimental trials, as suggested by Weidlich et al. (2020), are crucial for developing control methods tailored to the characteristics of these invasive species and the resources available.

Furthermore, understanding the presence of indigenous tree seedlings in soil seed banks is crucial for setting restoration goals in infested areas. Mechanical removal of IAS, such as clearings of *A. mearnsii*, can facilitate passive regeneration of woody species (Brancalion et al., 2017), such as

*Croton macrostachyus*, *Macaranga kilimandscharica*, and *Syzygium guineense* in the lower montane forest of Kilimanjaro National Park. Given the relatively low diversity of native woody seeds in the soil seed bank, forest enrichment with indigenous trees becomes highly relevant (Weidlich et al., 2020). According to Brancalion et al. (2017) establishing secondary forests with pioneer indigenous trees can help these species tolerate disturbances from emerging seedlings of the invasive species, particularly *A. mearnsii*.

To promote the development of indigenous trees and suppress further germination and growth of *A. mearnsii* from the soil seed bank, mechanical removal of IAS stems before flowering is essential (Kikoti, 2022). This approach can reduce the seed input into the soil seed bank, allowing native species to establish and thrive, ultimately supporting the restoration of the lower montane forest ecosystem (Weidlich et al., 2020).

## CONCLUSION

Assessment of soil seed banks in areas invaded by invasive alien species (IAS) is a necessary step in evaluating whether the soil seed bank can serve as a source of regeneration for native species from adjacent natural forests or if it will continue to harbour harmful invasive species. This study was critical for generating information pertinent to the management of IAS and the restoration of sites after the removal of alien species in the lower montane forest and similar ecosystems. The study revealed that the seed banks were dominated by herbaceous species, with families such as Asteraceae, Rubiaceae, Euphorbiaceae, and Oxalidaceae being prevalent. There was a low proportion of woody seedlings in the study sites, with dominant families including Fabaceae, Euphorbiaceae, Myrtaceae, and Proteaceae. The emergence of IAS seedlings, such as *A. mearnsii*, *A. longifolia*, *P. patula*, and *Grevillea robusta* in the lower montane forest, indicates a high risk of future invasion. In all studied sites, the top soils had the highest seed bank density, which decreased with increasing depth. The

*P. patula* site had the highest density of soil seed bank, whereas the natural forest site had a low soil seed bank density. This low density in the natural forest site may be due to seed dormancy, predation, and the quick germination of seeds from tropical forest trees. To address these findings, human intervention is suggested through the elimination of anthropogenic activities in the forest, removal of invasive alien species, and forest enrichment using indigenous trees. Further studies that focus on eliminating seed dormancy and comparing soil seed banks with above-ground vegetation are highly recommended. This approach will provide a more comprehensive understanding of the dynamics between seed banks and forest regeneration, ultimately aiding in the effective management and restoration of invaded ecosystems.

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### Author's Contributions

IAK came out with the concept and designed the study. He participated in data collection, analysis, interpretation and drafting of the manuscript. HJN advised on study design and data analysis and critically revised the manuscript. CJK and RMM assisted in data collection and identification of plant species. All authors read and approved the final manuscript.

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### Appendix 1: List of Plant Species Germinated from the Soil Seed Bank Experiments

SN	Plant species	Family	Growth habit	<i>Acacia mearnsii</i>	<i>Cupressus lusitanica</i>	<i>Eucalyptus sp.</i>	Natural Forest	<i>Pinus patula</i>
1	<i>Acacia longifolia</i> (Andr.) Willd.	Fabaceae	Woody	x	x	√	x	x
2	<i>Acacia mearnsii</i> De Wild.	Fabaceae	Woody	√	√	√	x	x
3	<i>Achyranthes aspera</i> Linn.	Amaranthaceae	Herb	x	√	√	√	√
4	<i>Ageratum conyzoides</i> L.	Asteraceae	Herb	√	√	√	√	√
5	<i>Alchemilla volkensii</i> Engl.	Rosaceae	Herb	x	√	x	x	x
6	<i>Alectra sessiliflora</i> (Vahl) Kuntze	Scrophulariaceae	Herb	√	x	√	x	√
7	<i>Aneilema aequinoctiale</i> (P.Beauv.) G.Don	Commelinaceae	Woody	√	√	√	x	x
8	<i>Anisopappus africanus</i> (Hook.f.) Oliv.&Hiern	Asteraceae	Woody	√	x	x	√	x
9	<i>Asplenium arcumontanum</i> Hemp &N.R	Aspleniaceae	Fern	x	x	x	x	x
10	<i>Begonia johnstonii</i> Oliv.ex Hook.f.	Begoniaceae	Woody	x	x	x	x	√
11	<i>Bidens pilosa</i> L.	Asteraceae	Herb	√	√	√	√	√
12	<i>Blotiella stipitata</i> (Alston) Faden	Denntaediaceae	Herb	x	x	x	√	x
13	<i>Bulbostylis densa</i> Wallich.	Cyperaceae	Sedge	x	x	x	x	√
14	<i>Capparis tomentosa</i> Lam	Capparaceae	Woody	x	x	√	x	x
15	<i>Cardamine africana</i> L.	Brassicaceae	Herb	x	x	x	√	x
16	<i>Cerastium afromontanum</i> T.C.Fr.	Caryophyllaceae	Herb	x	x	x	√	√
17	<i>Cerastium indicum</i> Wight&Arn.	Caryophyllaceae	Herb	√	√	√	√	√
18	<i>Cissus integrifolia</i> (Baker) Planch.	Vitaceae	Woody	√	x	√	x	x
19	<i>Commelina benghalensis</i> L.	Commelinaceae	Herb	√	x	x	x	x
20	<i>Conyza stricta</i> Willd.	Asteraceae	Herb	√	x	x	√	x

21	<i>Conyza bonariensis</i> (L.) Cronq.	Asteraceae	Herb	✓	✓	✓	✓	x
22	<i>Crassula alsinoides</i> (Hook.f.) Engl.	Crassulaceae	Herb	✓	✓	✓	x	✓
23	<i>Croton macrostachyus</i> Hochst.	Euphorbiaceae	Woody	x	✓	✓	x	✓
24	<i>Cyperus rigidifolius</i> Steud	Cyperaceae	Sedge	✓	✓	✓	✓	✓
25	<i>Cyperus rotundus</i> L.	Cyperaceae	Sedge	✓	✓	✓	✓	✓
26	<i>Cyphostemma kilimandscharicum</i> (Gilg) Desc. Ex Wild and R.B.Drumm	Vitaceae	Herb	x	x	x	x	✓
27	<i>Dichondra repens</i> J.R.Forst. & G.Forst.	Convolvulaceae	Herb	✓	✓	x	✓	✓
28	<i>Diclis bambuseti</i> R.E.Fries	Scrophulariaceae	Herb	x	✓	x	✓	x
29	<i>Dicrocephala integrifolia</i> (L.f. Kuntze	Asteraceae	Herb	✓	✓	✓	✓	x
30	<i>Digitaria velutina</i> (Forssk.)P.Beauv.	Poaceae	Grass	✓	x	✓	✓	x
31	<i>Dodonaea viscosa</i> Jacq.	Sapindaceae	Woody	x	✓	x	x	x
32	<i>Drymaria cordata</i> (L.) Willd. Ex Schult	Caryophyllaceae	Herb	✓	✓	✓	✓	✓
33	<i>Eragrostis aethiopica</i> Chiov.	Poaceae	Grass	✓	✓	✓	x	✓
34	<i>Eragrostis tenuifolia</i> (A.Ric) Hochst.exh	Poaceae	Grass	x	x	x	x	✓
35	<i>Euphorbia prostrata</i> Aiton	Euphorbiaceae	Herb	x	x	✓	x	x
36	<i>Exothea abyssinica</i> (Hochst. ex A. Rich.) Andersson	Poaceae	Grass	x	x	x	✓	✓
37	<i>Fimbristylis dichotoma</i> (L.) Vahl	Cyperaceae	Sedge	a	x	✓	x	✓
38	<i>Galinsoga parviflora</i> Cav.	Asteraceae	Herb	✓	✓	✓	✓	✓
39	<i>Galium scioanum</i> Chiov	Rubiaceae	Herb	✓	✓	✓	✓	✓
40	<i>Galium thunbergianum</i> Eckl.&Zeyh.	Rubiaceae	Herb	x	x	✓	x	x
41	<i>Gnaphalium pensylvanicum</i> (Willd.) Cabrera	Asteraceae	Herb	✓	✓	✓	✓	✓
42	<i>Grevillea robusta</i> A.Cunn.ex R.Br.	Proteaceae	Woody	✓	✓	x	x	✓
43	<i>Helichrysum foetidum</i> (L.) Moench	Asteraceae	Herb	✓	x	x	x	✓
44	<i>Helichrysum kilimanjari</i> Oliv.	Asteraceae	Herb	x	x	x	x	✓
45	<i>Helichrysum sp.</i> Mill.	Asteraceae	Shrub	x	x	✓	x	x
46	<i>Hydrocotyle sibthithopioides</i> Lam.	Amaranthaceae	Herb	✓	✓	✓	x	✓
47	<i>Kalanchoe densiflora</i> Rolfe	Crassulaceae	Herb	x	x	✓	x	✓
48	<i>Kyllinga odorata</i> Vahl	Cyperaceae	Sedge	✓	✓	✓	✓	✓
49	<i>Lepidium virginicum</i> L	Brassicaceae	Herb	x	x	x	✓	x
50	<i>Lindernia abyssinica</i> Engl.	Scrophulariaceae	Herb	✓	x	✓	x	x
51	<i>Lindernia parviflora</i> (Roxb.) Haines	Scrophulariaceae	Herb	✓	x	x	x	✓
52	<i>Loudetia simplex</i> (Nees) C.E.Hubb.	Poaceae	Grass	x	✓	x	x	x

53	<i>Lycopersicon esculentum</i> Mill.	Solanaceae	Herb	x	√	x	x	x
54	<i>Macaranga kilimandscharica</i> Pax	Euphorbiaceae	Woody	√	x	√	√	x
55	<i>Marchantia berteroana</i> Lehm.&Lindenb.	Marchantiaceae	Liverwort	x	x	x	√	x
56	<i>Monopsis stellarioides</i> (Urb.) E. Wimm	Lobeliaceae	Herb	√	√	√	√	√
57	<i>Oldenlandia corymbosa</i> L	Rubiaceae	Herb	√	√	√	√	√
58	<i>Olea</i> sp. L	Oleaceae	Woody	x	x	x	√	x
59	<i>Oxalis corniculata</i> L.	Oxalidaceae	Herb	x	x	x	√	x
60	<i>Oxalis corniculata</i> L.	Oxalidaceae	Herb	√	√	√	√	√
61	<i>Oxalis latifolia</i> Kunth	Oxalidaceae	Herb	x	x	x	√	x
62	<i>Oxygonum sinuatum</i> (Hochst.&Steud.ex Meisn.)	Polygonaceae	Herb	x	x	√	x	x
63	<i>Panicum protractum</i> Mez	Poaceae	Grass	√	√	√	x	√
64	<i>Panicum trichocladum</i> K.Schum	Poaceae	Grass	√	√	√	√	√
65	<i>Pellaea calomelanos</i> (Sw.) Link	Adiantaceae	Fern	√	x	√	√	x
66	<i>Pellaea viridis</i> (Forssk.) Prantl	Adiantaceae	Fern	x	x	x	√	x
67	<i>Pellaea</i> sp. (Forssk.) Prantl	Adiantaceae	Fern	x	x	x	x	x
68	<i>Pennisetum clandestinum</i> Hochst. Ex Chiov	Poaceae	Grass	x	x	x	√	x
69	<i>Pentas parvifolia</i> Hiern	Rubiaceae	Herb / Woody	x	√	√	x	x
70	<i>Peperomia abyssinica</i> Miq	Piperaceae	Herb	x	x	x	x	√
71	<i>Peperomia tetraphylla</i> (G.Forst.) Hook.&Arn.	Piperaceae	Herb	x	x	x	x	√
72	<i>Phyllanthus amarus</i> Schumach.&Thonn.	Euphorbiaceae	Herb	x	x	x	√	√
73	<i>Phyllanthus fischeri</i> Pax	Euphorbiaceae	Herb / Woody	√	√	√	√	√
74	<i>Pilea johnstonii</i> Oliv.	Urticaceae	Herb	x	x	x	√	x
75	<i>Pinus patula</i> Schied ex Schltdl.&Cham.	Pinaceae	Woody	x	x	x	x	√
76	<i>Plectranthus fruticosus</i> L' Her.	Lamiaceae	Herb/woody	√	√	√	√	√
77	<i>Poa annua</i> L	Poaceae	Grass	x	x	√	x	√
78	<i>Polystachya kilimanjari</i> Kraenzi	Orchidaceae	Herb	x	√	x	x	x
79	<i>Plectranthus</i> sp. L' Her.	Lamiaceae	Herb / woody	x	√	√	x	x
80	<i>Pteris catoptera</i> Kunze	Pteridaceae	Fern	√	x	x	√	x
81	<i>Richardia brassiliensis</i> Gomes	Rubiaceae	Herb	x	x	x	x	√
82	<i>Rubus apetalus</i> Poir	Rosaceae	Herb / woody	x	√	√	x	x
83	<i>Rubus keniensis</i> Standl.	Rosaceae	Herb / woody	x	√	x	x	√
84	<i>Sanicula elata</i> Buch.ex D.Don	Amaranthaceae	Herb	√	x	√	x	√
85	<i>Selaginella kraussiana</i> (Kunze) A.Braun	Sellaginellaceae	Herb	x	x	x	x	√
86	<i>Senecio syringifolius</i> O. Hoffm.	Asteraceae	Herb	√	x	√	x	x
87	<i>Setaria megaphylla</i> (Steud.T.Dur.&Schinz)	Poaceae	Grass	√	√	√	√	√



88	<i>Solanum nigrum</i> L.	Solanaceae	Shrub	x	√	x	√	x
89	<i>Sparrrmania ricinocarpa</i> (Eckl.&Zeyh.) Kuntze	Malvaceae	Herb	x	x	√	x	x
90	<i>Spermacoce princea</i> (K.Schum.) Verdc.	Rubiaceae	Herb	√	√	√	√	√
91	<i>Stellaria mannii</i> Hook.f.	Caryophyllaceae	Herb	x	x	x	√	√
92	<i>Stellaria sennii</i> Chiov	Caryophyllaceae	Herb	x	x	x	√	x
93	<i>Striga forbesii</i> Benth	Scrophulariaceae	Herb	x	√	x	x	x
94	<i>Syzygium guineense</i> Wall.	Myrtaceae	Woody	x	√	x	x	x
95	<i>Thunbergia alata</i> Bojer ex Sims	Acanthaceae	Herb	x	x	x	x	√
96	<i>Toddalia asiatica</i> (L) Lam.	Rutaceae	Woody	√	x	√	x	√
97	<i>Vernonia lasiopus</i> O.Hoffm.	Asteraceae	Herb	√	x	√	x	√
98	<i>Veronica abyssinica</i> Fresen	Scrophulariaceae	Herb	√	√	√	√	√
99	<i>Veronica javanica</i> Blume	Scrophulariaceae	Herb	√	√	√	√	√
100	<i>Zehneria Scabra</i> (Linn.f.) Sond	Cucurbitaceae	Herb	√	√	√	x	√