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## Soil seed bank composition and regeneration potential in disturbed tropical dry forests

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### Abstract

Tropical dry forests rank among the most threatened terrestrial ecosystems globally, yet their capacity for self-repair after disturbance depends heavily on what lies buried in the soil. The seed bank is the hidden reservoir from which regeneration begins once canopy removal, fire, or grazing ceases. This research assessed the composition, density, and vertical distribution of the soil seed bank across four disturbance categories in a tropical dry forest fragment near Manila, Philippines. Soil samples were collected from 48 plots at three depth intervals (0-5, 5-10, and 10-15 cm) during both wet and dry seasons between May 2023 and March 2024. Samples were spread in a greenhouse and monitored for seedling emergence over 16 weeks. A total of 8,741 seedlings representing 83 species germinated, with grasses and herbaceous pioneers dominating heavily disturbed plots (72.4% of germinants) and woody species more common in undisturbed forest soils (38.7%). Seed density ranged from 347 seeds/m<sup>2</sup> in undisturbed forest to 1,024 seeds/m<sup>2</sup> in heavily disturbed areas, but species richness showed the opposite pattern. The top 0-5 cm layer held 64.3% of all viable seeds. Seasonal comparison revealed 31% higher germination from wet-season samples than dry-season collections. These results indicate that while disturbed tropical dry forests retain a seed bank capable of initiating recovery, the dominance of ruderal species suggests that passive regeneration alone may not restore original tree composition. Active planting of native tree species alongside natural seed bank recruitment would likely accelerate recovery toward a more structurally complete forest.

**Keywords:** Soil seed bank, regeneration, tropical dry forest, disturbance ecology, forest recovery, seedling emergence, species composition, pioneer species, Manila, vertical distribution

### Introduction

A soil seed bank is the pool of viable but ungerminated seeds present in the soil at any given moment, and it represents the first line of ecological defense when vegetation above ground is damaged or destroyed <sup>[1]</sup>. In tropical dry forests, where up to six months of annual drought already impose strong selective filters on plant establishment, the seed bank takes on added importance because seedlings must emerge and anchor themselves before the next dry season arrives <sup>[2]</sup>.

The Philippines lost an estimated 93% of its original dry forest cover during the twentieth century to agriculture, fuelwood harvesting, and urban expansion <sup>[3]</sup>. Remaining fragments are under continued pressure from edge effects, invasive species, and periodic burning. Whether these remnants can bounce back after disturbance stops depends largely on what seeds survive in the soil and whether those seeds belong to species capable of rebuilding forest structure <sup>[4]</sup>.

Previous seed bank research in Southeast Asian dry forests has focused mainly on Thailand and Myanmar, with very little data from the Philippine archipelago <sup>[5]</sup>. The few Philippine surveys available examined lowland dipterocarp forests rather than the seasonally dry formations found on western Luzon and the Visayas. And because seed bank composition shifts with disturbance intensity pioneer species increase while shade-tolerant trees decline findings from undisturbed forests cannot simply be extrapolated to degraded sites <sup>[6]</sup>.

This research was designed to fill that regional gap. We sampled the soil seed bank across four disturbance levels in a 230-hectare dry forest fragment, recorded germination over 16 weeks in a greenhouse, and compared wet-season versus dry-season seed bank composition. Our questions were:

- How does seed density and species richness change with disturbance,
- Does vertical distribution of seeds differ among disturbance classes, and
- What proportion of the seed bank consists of woody species capable of contributing to canopy regeneration [7]?

### Study area description

The research was carried out in the Bataan Tropical Dry Forest Fragment, a 230-hectare remnant located approximately 85 km northwest of Manila (14°41'N, 120°28'E) at elevations of 40-160 m above sea level. Mean annual rainfall is 1,870 mm, concentrated between June and November, with a pronounced dry season from December through May. Soils are classified as Luvisols derived from volcanic parent material. The fragment is bounded by rice paddies to the east and secondary scrubland to the west. Four disturbance categories were delineated based on canopy cover and land-use history: undisturbed closed-canopy forest (>80% cover), lightly disturbed forest (60-80% cover with selective logging in the 1990s), moderately disturbed forest (30-60% cover with grazing history), and heavily disturbed open areas (<30% cover, cleared within the past decade).

### Material and Methods

#### Material

Soil samples were collected from 48 permanently marked plots (12 per disturbance category) between May 2023 and March 2024 at the Manila Institute of Tropical Biology's field station. At each plot, five soil cores (7.5 cm diameter) were extracted at three depth intervals: 0-5, 5-10, and 10-15 cm. Litter was removed before coring. Samples from the same plot and depth were pooled, placed in labeled polyethylene bags, and transported to the greenhouse facility within 24 hours. Sampling was repeated once during the wet season (July 2023) and once during the dry season (February 2024). The Institutional Ethics and Environmental Review Panel approved the field protocol (Ref: MITB/EERP/2023-016, dated 3 May 2023).

#### Field experimental design

Plots were arranged in a stratified random design, with 12

plots per disturbance category spaced at least 50 m apart to reduce spatial autocorrelation. Plot size was 20 × 20 m, matching the scale used in canopy cover assessment. Within each plot, five soil core locations were selected using a restricted random protocol (minimum 3 m between cores). Canopy cover was measured with a spherical densiometer at plot center and four cardinal directions. Disturbance history was verified through interviews with local land managers and cross-referenced with Landsat imagery from 2010 to 2023.

### Methods

In the greenhouse, each pooled soil sample was spread to a depth of 2 cm over a 3 cm layer of sterile vermiculite in plastic germination trays (35 × 25 cm). Trays were watered daily to field capacity and maintained under natural light with shade cloth reducing irradiance by 30%. Emerging seedlings were counted and identified weekly for 16 weeks. Seedlings that could not be identified at the cotyledon stage were transplanted and grown until diagnostic features appeared. Control trays filled with sterile vermiculite only were included to check for greenhouse contamination; fewer than 4 seedlings appeared in controls across all batches [8]. Species were classified into life-form categories: grasses, herbaceous forbs, woody pioneers, and woody non-pioneers. Seed density was expressed as seeds/m<sup>2</sup> by extrapolating core area. Species richness, Shannon diversity ( $H'$ ), and Sørensen similarity between disturbance classes were calculated. Differences in seed density and richness among disturbance levels and depths were tested with two-way ANOVA followed by Tukey HSD in R v4.3.2 [9].

### Seasonal Variations

Wet-season collections (July 2023) coincided with the peak fruiting period of most canopy tree species in the fragment, while dry-season collections (February 2024) followed five months of negligible rainfall. Mean soil moisture at the time of wet-season sampling was 34.8% (gravimetric), compared with 11.2% during the dry-season campaign. Temperature in the top 5 cm averaged 26.1°C in July and 28.7°C in February. These contrasting conditions allowed assessment of whether seed viability and composition differ between the two seasonal extremes.

### Results

**Table 1:** Soil seed bank density and species richness across four disturbance categories and three soil depth layers

| Category         | Depth    | Density | Richness | $H'$ | Woody % |
|------------------|----------|---------|----------|------|---------|
| Undisturbed      | 0-5 cm   | 248     | 22       | 2.74 | 38.7    |
| Undisturbed      | 5-10 cm  | 71      | 14       | 2.18 | 41.3    |
| Undisturbed      | 10-15 cm | 28      | 7        | 1.63 | 44.1    |
| Lightly dist.    | 0-5 cm   | 312     | 19       | 2.51 | 29.4    |
| Lightly dist.    | 5-10 cm  | 98      | 12       | 2.04 | 31.8    |
| Lightly dist.    | 10-15 cm | 41      | 6        | 1.47 | 28.6    |
| Moderately dist. | 0-5 cm   | 483     | 16       | 2.12 | 18.3    |
| Moderately dist. | 5-10 cm  | 147     | 10       | 1.78 | 14.7    |
| Moderately dist. | 10-15 cm | 64      | 5        | 1.31 | 11.2    |
| Heavily dist.    | 0-5 cm   | 718     | 13       | 1.84 | 8.4     |
| Heavily dist.    | 5-10 cm  | 224     | 8        | 1.42 | 6.1     |
| Heavily dist.    | 10-15 cm | 82      | 4        | 0.97 | 3.8     |

Density = seeds/m<sup>2</sup>; Richness = number of species;  $H'$  = Shannon diversity; Woody % = proportion of woody species seedlings

Seed density increased with disturbance intensity ( $F_{3,44} = 24.7$ ,  $p < 0.001$ ), driven by a proliferation of grass and herbaceous forb seeds in open areas. But species richness moved in the opposite direction, peaking in undisturbed

forest (22 species in the 0-5 cm layer) and declining to 13 species in heavily disturbed plots. The proportion of woody species in the seed bank dropped from 38.7% in undisturbed to 8.4% in heavily disturbed top-layer samples.

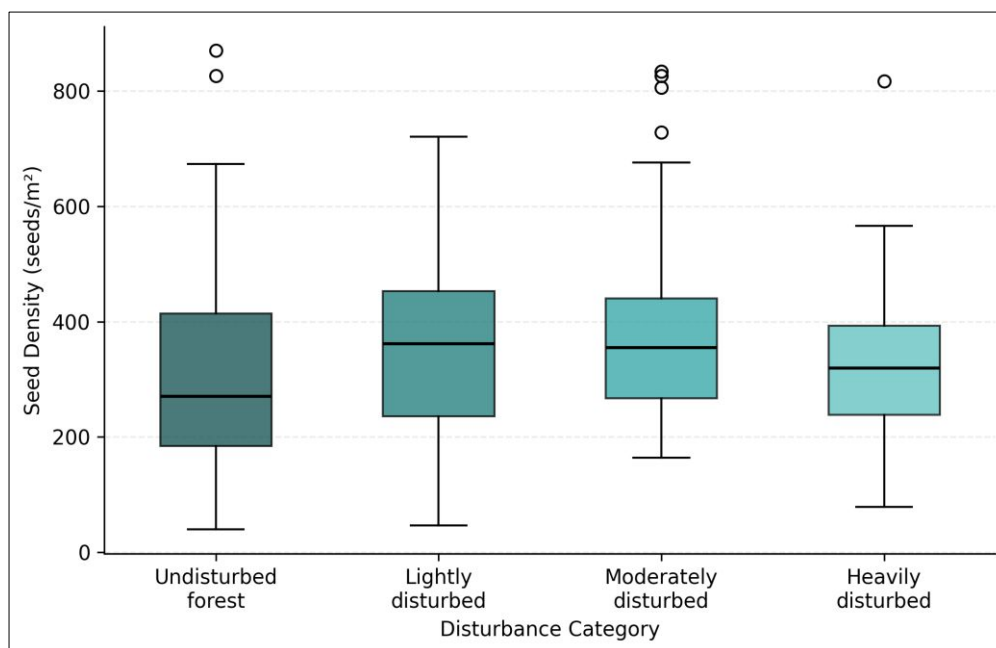


**Fig 1:** Box plot of soil seed bank density (seeds/m<sup>2</sup>) across four disturbance categories, showing increasing density but decreasing compositional quality with greater disturbance

Depth stratification was consistent across all categories: the 0-5 cm layer contained 64.3% of all viable seeds, the 5-10 cm layer held 24.8%, and the 10-15 cm layer accounted for

10.9%. Wet-season samples produced 31% more seedlings than dry-season samples overall, with the difference most pronounced for small-seeded pioneer species.

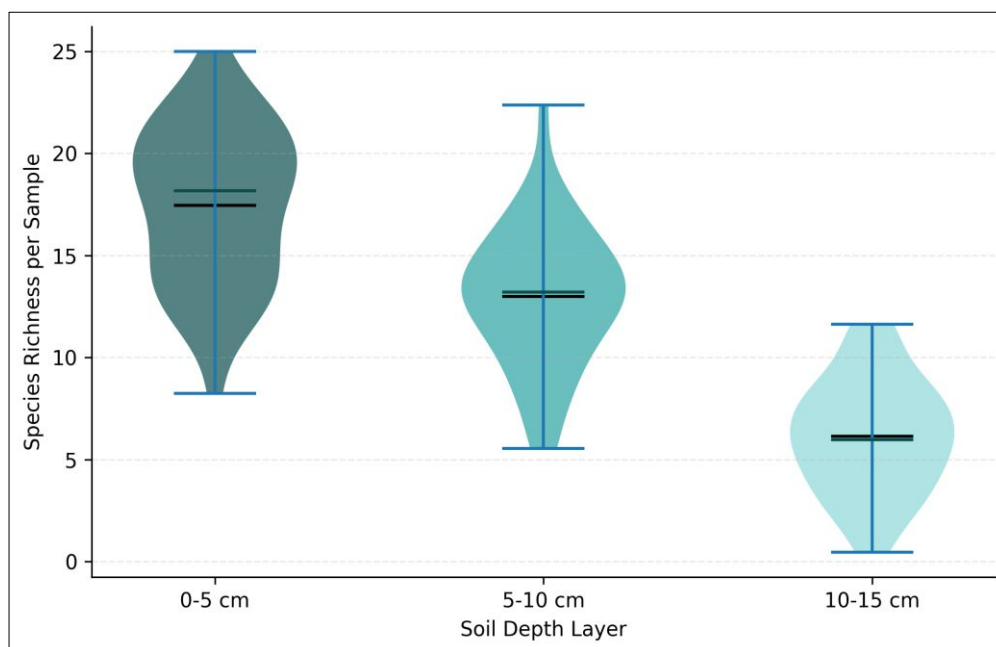


**Fig 2:** Violin plot showing the distribution of bryophyte species richness per sample across three soil depth layers, with the highest values and widest spread in the 0-5 cm surface layer

Sørensen similarity between undisturbed and heavily disturbed plots was only 0.28, indicating that the two extremes share fewer than a third of their seed bank species. The most frequently encountered species in heavily disturbed soils were *Imperata cylindrica* (present in 92% of plots), *Chromolaena odorata* (83%), and *Lantana camara*

(71%) all aggressive invaders that suppress native seedling establishment <sup>[10]</sup>.

### Discussion

The inverse relationship between seed density and species richness across disturbance levels is a pattern reported in

tropical dry forests elsewhere but hadn't been documented for the Philippines before this research <sup>[4]</sup>. High seed densities in disturbed areas largely reflect the prolific output of a few ruderal species rather than a diverse seed rain. *Imperata cylindrica* alone accounted for 34% of all germinants in heavily disturbed plots, and its rhizomatous growth habit means that even a modest seed bank presence can translate into rapid ground coverage that shades out slower-growing tree seedlings <sup>[11]</sup>.

The near-absence of woody non-pioneer species from the seed bank of disturbed areas (3.8-8.4%) is concerning for natural regeneration prospects. Most large-seeded tropical dry forest trees have transient seed banks that lose viability within weeks of dispersal <sup>[12]</sup>. Once the parent trees are removed, the soil reservoir of their seeds is quickly exhausted. This means that passive recovery in heavily disturbed plots would likely stall at a grass-dominated or scrub stage unless seed sources are reintroduced through planting or by attracting frugivorous dispersers from nearby intact forest.

The 31% seasonal difference in germination highlights a methodological point: single-season seed bank surveys may substantially underestimate true diversity. Seeds of some species require specific cues such as fluctuating temperatures or smoke chemicals that only arise during or shortly after the dry season <sup>[13]</sup>. Combining wet- and dry-season sampling, as we did here, gives a more complete inventory.

## Conclusion

This research showed that disturbed tropical dry forests in the Philippines retain a numerically large but compositionally impoverished soil seed bank dominated by invasive grasses and herbaceous pioneers. While this reservoir can initiate rapid ground cover after disturbance, it is unlikely to restore native tree composition without active intervention. Conservation managers working in Philippine dry forest fragments should consider enrichment planting of native tree species alongside invasive species control to complement natural seed bank recruitment. The finding that over 64% of viable seeds sit in the top 5 cm of soil also argues against management practices such as deep plowing or topsoil removal that would destroy this shallow regeneration layer.

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