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Articles

Soil seed bank in a forest area affected by logging in the Jamari National Forest, Rondônia state, Brazil

Banco de sementes do solo em uma área florestal afetada pelo corte de árvores na Floresta Nacional de Jamari, estado de Rondônia, Brasil

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ABSTRACT

The soil seed bank is an important ecological indicator of forest resilience following disturbance. This study evaluated the composition and structure of the soil seed bank in areas affected by logging in the Jamari National Forest (Flona do Jamari), Brazilian Amazon. Soil samples were collected at a depth of 5 cm using a 25 x 25 cm iron frame in two environments: logging decks (L) used for timber extraction in 2010 (n = 20), and undisturbed forest (F) used as controls (n = 20). Samples were monitored for 11 months in a shade house, and all emerging seedlings were quantified, identified, and classified by life form and ecological group. Floristic dissimilarity between environments was evaluated via the Bray-Curtis index, while differences were tested using the student's t-test. Seedling density was higher in the undisturbed forest (580 seedlings m^{-2}; 27 species) than in the logging decks (420 seedlings m^{-2}; 23 species). Asteraceae, *Bellucia grossularioides*, and herbaceous and pioneer species were dominant in both environments. Although only partial floristic similarity was observed, eight years after disturbance the soil seed bank in logged areas showed patterns comparable to those of undisturbed forest.

Keywords: Conservation units; Sustainable forest management; Natural regeneration mechanisms; Successional groups

RESUMO

O banco de sementes do solo é um importante indicador ecológico da resiliência florestal após perturbações. Este estudo avaliou a composição e a estrutura do banco de sementes do solo em áreas afetadas pela exploração madeireira na Floresta Nacional do Jamari (Flona do Jamari), na Amazônia brasileira. Amostras de solo foram coletadas a uma profundidade de 5 cm usando uma estrutura de ferro de 25 x 25 cm em dois ambientes: pátios de estocagem (L) usados para extração de madeira em 2010 (n = 20) e floresta não perturbada (F) usada como controle (n = 20). As amostras foram monitoradas por 11 meses em uma casa de sombra, e todas as mudas emergentes foram quantificadas, identificadas e classificadas por forma de vida e grupo ecológico. A dissimilaridade florística entre os ambientes foi avaliada através do índice de Bray-Curtis, enquanto as diferenças foram testadas utilizando o teste t de Student. A densidade de mudas foi maior na floresta não perturbada (580 mudas m^{-2}; 27 espécies) do que nos pátios de estocagem (420 mudas m^{-2}; 23 espécies). Asteraceae, Bellucia grossularioides e espécies herbáceas e pioneiras foram dominantes em ambos os ambientes. Embora tenha sido observada apenas uma semelhança florística parcial, oito anos após a perturbação, o banco de sementes do solo nas áreas exploradas apresentou padrões comparáveis aos da floresta não perturbada.

Palavras-chave: Unidades de conservação; Manejo florestal sustentável; Mecanismos de regeneração natural; Grupos sucessionais

1 INTRODUCTION

Logging creates canopy gaps in native forests, promoting the regeneration of shade-intolerant species. However, tree felling and the operation of heavy machinery cause varying degrees of damage depending on logging intensity (Schwartz et al., 2017), which directly affects gap recovery time (Puig, 2008). In highly disturbed areas, such as logging decks—where vegetation is entirely removed, topsoil stripped, and soil compacted by machinery and log storage—natural regeneration mechanisms, including seedling recruitment and the soil seed bank, are often severely reduced or eliminated.

The soil seed bank comprises viable propagules in the soil and litter and functions as a dynamic system regulated by inputs, such as seed rain linked to fruiting seasonality, and outputs, including germination, predation, and viability loss. This mechanism plays a central role in regeneration processes in canopy gaps, forest edges, and deforested areas (Almeida, 2016; Duarte et al., 2022), and is strongly influenced by local vegetation composition, disturbance history, and landscape context (Bordan; Natali; Leal, 2021).

In preserved and restored forests alike, the soil seed bank provides insight into vegetation dynamics by indicating species that persist after disturbance and drive early-successional regeneration, even within mature forest stands (Martins, 2010). It is therefore widely used as an indicator of ecological quality in restored ecosystems, post-disturbance forest recovery, edge effects, and the impacts of climate change (Miranda Neto et al., 2014; Silva et al., 2021; Douh et al., 2023). Its application in the restoration of degraded areas is particularly valuable, since it offers a cost-effective means of promoting regeneration based on locally adapted genetic material (Correia & Martins, 2015; Chazdon; Guariguata, 2016; O'Donnell et al., 2016; Oliveira et al., 2018).

Given this context, understanding the composition and density of the soil seed bank is essential for interpreting ecological dynamics in disturbed forests and supporting conservation strategies at the community level (Franco et al., 2012; Leal Filho et al., 2013). Accordingly, this study used the soil seed bank to evaluate forest resilience eight years after logging in the Jamari National Forest (FLONA Jamari), Rondônia state (RO), Brazil.

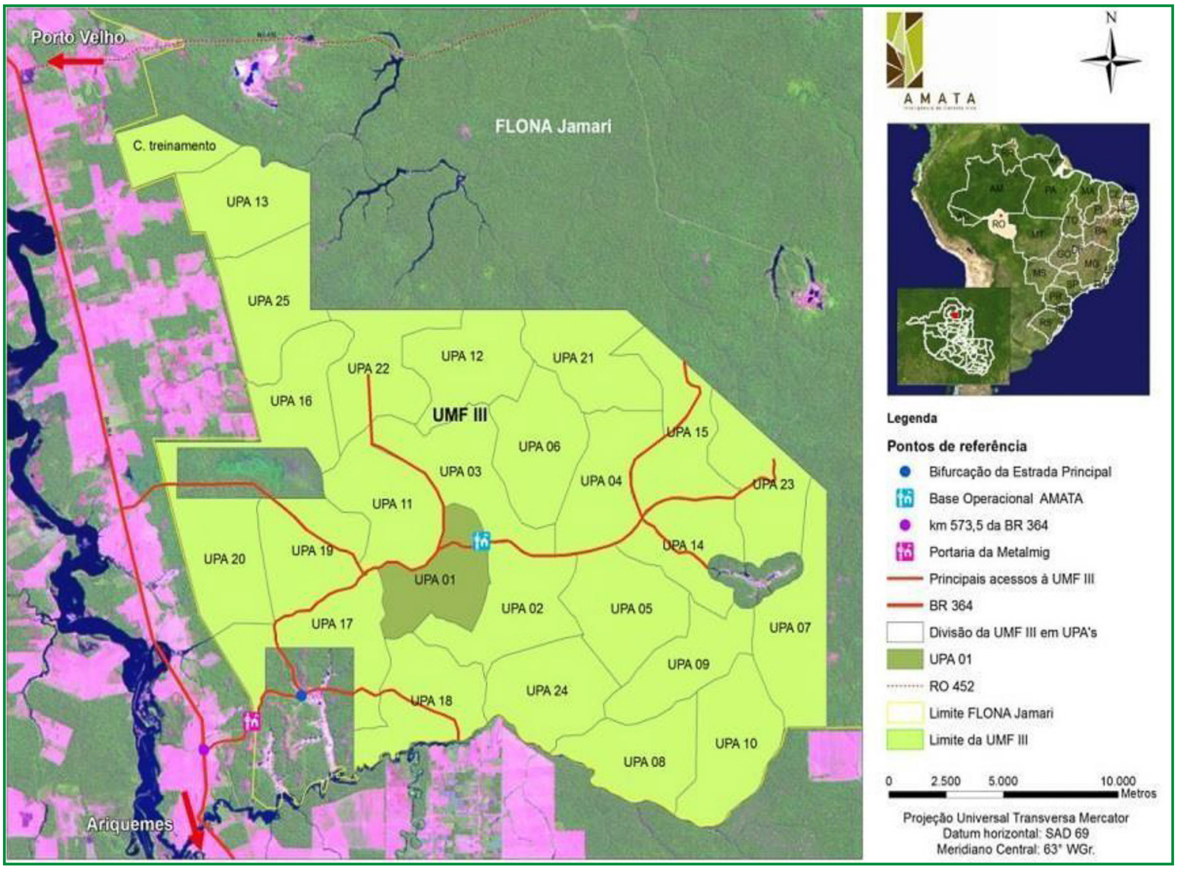
2 MATERIALS AND METHODS

2.1 Study area location and characterization

The study was carried out in Annual Production Unit (UPA) 01, which is part of Forest Management Unit (UMF) III in the Jamari National Forest (FLONA Jamari), located in Rondônia state, Brazil (Figure 1).

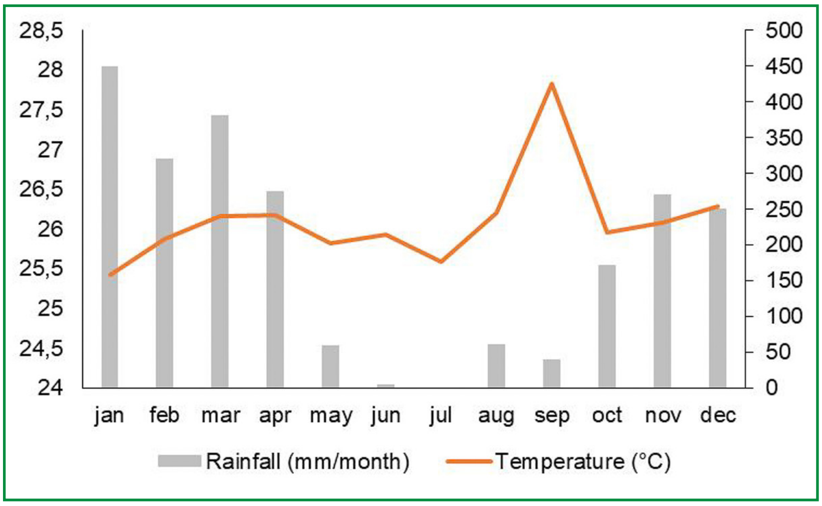
The regional climate is tropical monsoon (Am), characterized by a marked dry season between June and August (Alvares et al., 2013). Climate data from the National Institute of Meteorology (INMET, 2024) indicate that during the sampling year (2019), the mean annual temperature was approximately 26°C, while monthly rainfall ranged from 0.6 mm to 497.6 mm (Figure 2). The study area is dominated by Open Ombrophilous Forest, a transitional vegetation formation between Amazon rainforest and extra-Amazonian domains (IBGE, 2012).

Figure 1 – Geographic location of Annual Production Unit (UPA) 01 in Forest Management Unit (UMF) III in the Jamari National Forest (Flona Jamari), Rondônia, Brazil



Source: AMATA (2014)

Figure 2 – Monthly total rainfall and mean temperature recorded at the A940 meteorological station in Ariquemes, Rondônia, Brazil, during 2019



Source: INMET (2024)

UPA 01 was harvested between 2010 and 2011 and encompasses a total area of 1,586 ha, of which 1,359 ha were effectively logged. During this period, 19,528 m³ of timber were extracted, resulting in an average logging intensity of 14.4 $m^3\ ha^{-1}$. Harvested areas were supported by management infrastructure, including primary and secondary roads, logging decks, and skidding trails.

Logging decks (measuring 20 x 25 m) were constructed along secondary roads in accordance with Administrative Norm No. 1 of April 24, 2007 (Brasil, 2007). These areas were cleared by bulldozers, which removed vegetation and the upper soil layers (O and A horizons). During harvest operations, machinery traffic, log transport, and log storage caused substantial soil compaction (Figure 3).

Figure 3 – Logging deck during timber harvest operations in the Jamari National Forest (Flona do Jamari), Rondônia, Brazil

Source: Authors (2022)

2.2 Data collection

Soil samples for seed bank assessment (n = 40) were collected between March and April 2019, corresponding to the onset of the regional dry season. Sampling encompassed two environments: logging decks (L) established during the 2010 harvest operations (n = 20) and undisturbed forest plots (F: n = 20) used as controls, located 25 m from the edges of logging deck under intact forest canopy. Samples were extracted to a depth of 5 cm using a 25 x 25 cm iron frame.

All samples were bagged, labeled, and transported to a shaded nursery with 50% shade cloth at the Federal University of Rondônia (Rolim de Moura Campus). In the nursery, samples were placed in perforated plastic trays (45.0 × 28 × 7.7 cm) containing a 30-cm layer of washed and solarized sand to ensure adequate drainage and prevent waterlogging. Irrigation was applied as needed whenever the soil surface became dry.

The soil seed bank was monitored every two weeks using the indirect germination method. All emerged seedlings were counted, identified, and removed. Individuals that could not be identified were transplanted into plastic bags and maintained until identification was possible. Samples remained in the nursery from April 2019 to March 2020, after which seedling emergence declined. At this stage, the soil was disturbed to assess the potential for additional germination.

Species identification followed the Angiosperm Phylogeny Group system (APG IV, 2016), and taxonomic nomenclature was verified using bibliographic sources and the Flora do Brasil 2020 database (Flora do Brasil, 2020).

2.3 Data analysis

Species richness was quantified as the total number of families, genera, and species (Felfili & Venturoli, 2000). Seedling density was expressed as absolute density (seedlings m^{-2}). Differences in seedling density and richness between environments were tested using independent-samples t-tests.

Florisitic dissimilarity between environments was calculated using the Bray-Curtis index based on species-level seedling densities. Patterns of species composition were visualized through non-metric multidimensional scaling (nMDS) using the "metaMDS" function of the "vegan" package in R software (Oksanen et al., 2020). Species were classified by life form according to Flora do Brasil (2020), and ecological groups were assigned following Budowski (1965).

3 RESULTS AND DISCUSSION

A total of 1,250 seedlings emerged across two environments: logging decks (L) and undisturbed forest (F) (Table 1). These seedlings comprised 32 species distributed across 18 genera and 11 families, in addition to 13 morphospecies.

Table 1 – Floristic composition and seedling density of the soil seed bank in a logging deck area eight years post-logging (L) and an undisturbed forest area (F) in Flona do Jamari, RO

Family	Species	N	AD_F	AD_P	EG	LF
Asteraceae	*Ambrosia artemisiifolia* L.	13	4.0	6.4	NC	H
	Emilia fosbergii Nicolson	55	17.6	26.4	Pi	H
	Praxelis pauciflora (Kunth) R. M. King & H. Rob.	6	2.4	2.4	NC	H
	Vernonia polyanthes Less.	2	1.6	-	Pi	Sh
Cyperaceae	*Cyperus rotundus* L. (CYPRO)	107	40	45.6	Pi	H
Euphorbiaceae	*Chamaesyce hirta* (L.) Milisp.	1	-	0.8	NC	H
Fabaceae	*Apuleia leiocarpa* (Vogel) J.F.Macbr.	4	3.2		LS	A
	Bauhinia variegata L.	2	1.6		Pi	A
	Parkia sp.	64	32.8	18.4	Pi	A
Goupiaceae	*Goupia glabra* Aubl.	5	4.0		Pi	A
Melastomataceae	*Bellucia grossularioides* (L.) Triana	375	276.8	23.2	Pi	A
	Miconia ampla Triana	10	1.6	6.4	Pi	Sh
Muntingiaceae	*Muntingia calabura* L.	9	4.0	3.2	Pi	A
Phyllanthaceae	*Phyllanthus tenellus* Roxb.	139	60.8	50.4	LS	H
Poaceae	*Cynodon dactylon* (L) Pers	150	12.8	107.2	NC	H
	Cynodon sp.	87	18.4	51.2	NC	H
Rubiaceae	*Calycophyllum spruceanum* (Benth.) K.Schum.	33	22.4	4.0	Pi	A
Urticaceae	*Cecropia* sp.	11	8.8	-	Pi	A
	Pourouma bicolor Mart.	22	16.0	1.6	Pi	A
	Morphospecies	155	51.2	72.8	-	-
Total		1250	580.0	420.0		

Source: Authors (2025)

In where: N = total number of individuals; AD = absolute density (seedlings m^{-2}); F = undisturbed forest; L = logging deck; EG = ecological group (Pi = pioneer; ES = early secondary; LS = late secondary; NC = not classified); LF = life form; H = herbaceous; Sh. = shrub; A = arboreal.

Overall, seedling density and floristic composition did not differ significantly among the studied environments ($p > 0.05$) (Table 2).

Table 2 – Seedling density and floristic richness of the soil seed bank in Annual Production Unit 01, in the Jamari National Forest (Flona do Jamari), Rondônia, Brazil

Variables	Undisturbed forest	Logging deck	p-value test
AD (seedlings m^{-2})	580	420	0.1533^{ns}
No. of emerged seedlings	725	525	
No. of species	27	23	0.0751^{ns}
No. of genera	17	13	
No. of families	10	10	

Source: Authors (2025)

In where: AD = absolute density; No. = number; NS = not significant by the t-test ($p = 0.05$).

Consistent with our results, Douh et al. (2023) found no significant differences in mean seed densities between sites harvested 13 years earlier and recently harvested areas in tropical humid forests of the Republic of Congo. Quanz et al. (2012) reported similar seed densities across conserved, recently harvested, and one-year post-harvest areas in the Brazilian Amazon. These findings suggest that logging activities did not necessarily lead to marked reductions in quantity of seeds stored in the soil.

Previous studies have reported mean soil seed bank densities of approximately 500 seeds m^{-2} in primary tropical forests (Saulei; Swaine, 1988; Correia; Martins, 2015). In the present study, seedling densities observed in both environments within the Jamari National Forest were comparable to these reference values, including areas affected by logging. This indicates that, under the conditions studied, soil seed bank functionality can be restored once the disturbance agents are removed.

In managed forests, logging decks and roads are typically established one year prior to timber extraction. Following harvest operations, these areas remain fallow until the next cutting cycle and usually do not receive silvicultural treatments. However, field observations revealed abundant natural regeneration in more recently harvested sites (one-year post-harvest) (Figure 4), even in logging decks that remain compacted, as reported by Montagnolli et al. (2024). This underscores the high resilience of tropical forests to disturbances associated with forest management.

Figure 4 – Logging deck one year after logging operations in the Jamari National Forest (Flona Jamari), Rondônia, Brazil

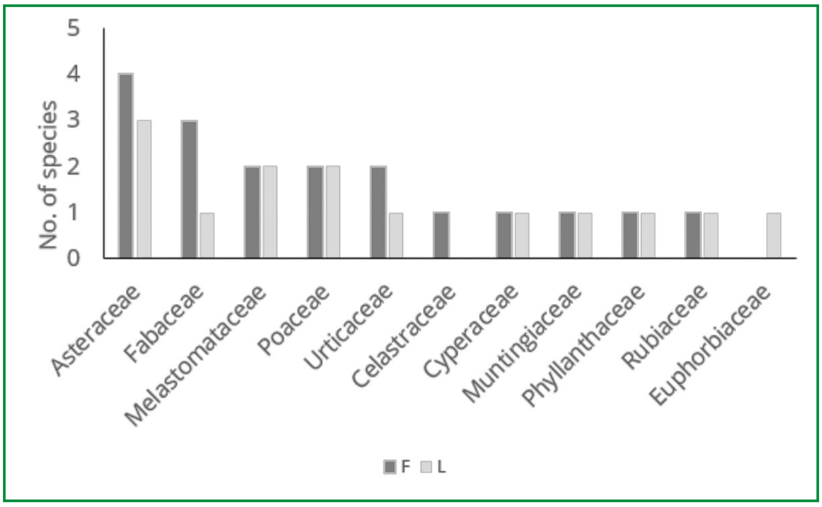
Source: Authors (2022)

Asteraceae exhibited the highest species richness family in both evaluated environments (Figure 5). In undisturbed forest areas (F), Fabaceae was the second most species-rich family—a pattern that is widely documented in floristic surveys of Amazonian Open Ombrophilous Forests (Andrade et al., 2015; Lima et al., 2019; Kerber et al., 2021).

The botanical families most frequently represented in the soil seed bank across both environments have also been reported as highly species-rich by Sccoti and Monteiro (2023) in an Open Ombrophilous Forest in Rondônia, and by Franco et al.

(2012) in a fragment of Secondary Semideciduous Seasonal Forest in Viçosa, Minas Gerais. In addition, Poaceae has been highlighted as a key family in mitigating soil erosion processes (Ferreira et al., 2014).

Figure 5 – Species richness by botanical family in soil seed banks from undisturbed forest (F) and logging decks areas (L) in the Jamari National Forest, Rondônia, Brazil



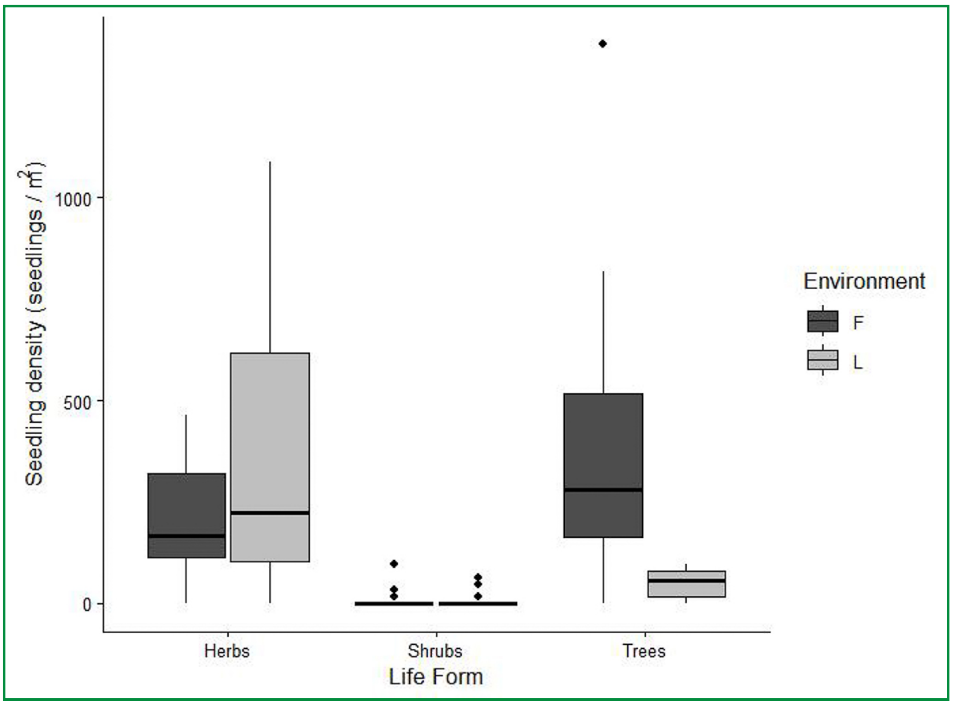
Source: Authors (2025)

Floristic composition differed between environments, with higher species richness recorded in the undisturbed forest (F; 27 species). This environment was characterized by high seedling densities from *Bellucia grossularioides*, *Phyllanthus tenellus*, *Cyperus rotundus*, *Parkia sp*., and *Calycophyllum spruceanum*. By contrast, environment L contained 23 species and was dominated by *Cynodon dactylon*, *Cynodon sp*., *Phyllanthus tenellus*, *Cyperus rotundus*, and *Emilia fosbergii* (all herbaceous). The species richness observed in both environments falls within the range of 8 to 67 species reported by Garwood (1989) for tropical forests and is consistent with other studies conducted in the Brazilian Amazon (Quanz et al., 2012; Sousa et al., 2017).

Tree species were more abundant in the F environment, with *Bellucia grossularioides* occurring in 90% of samples, highlighting its pioneer regeneration capacity (Sousa et al., 2017). Other timber species, including *Goupia glabra* (cupiúba) and *Apuleia leiocarpa* (garapeira), were also recorded.

Tree seedling density was higher in F (369.6 seedlings m⁻²), whereas herbaceous seedling density predominated in L (204 seedlings m⁻²) (Figure 6). Herbaceous species play an essential ecological role in forest regeneration, contributing to rapid soil cover, organic matter accumulation, enhanced soil moisture retention, and reduced erosion (Martins et al., 2021). In addition, some herbaceous taxa may act as phytoremediators in degraded or polluted environments (Rodelovic; Slobodan, 2023).

Figure 6 – Absolute seedling density (AD) by life form in undisturbed forest (F) and logging decks (L) based on soil seed bank data from the Jamari National Forest (Flona do Jamari), Rondônia, Brazil



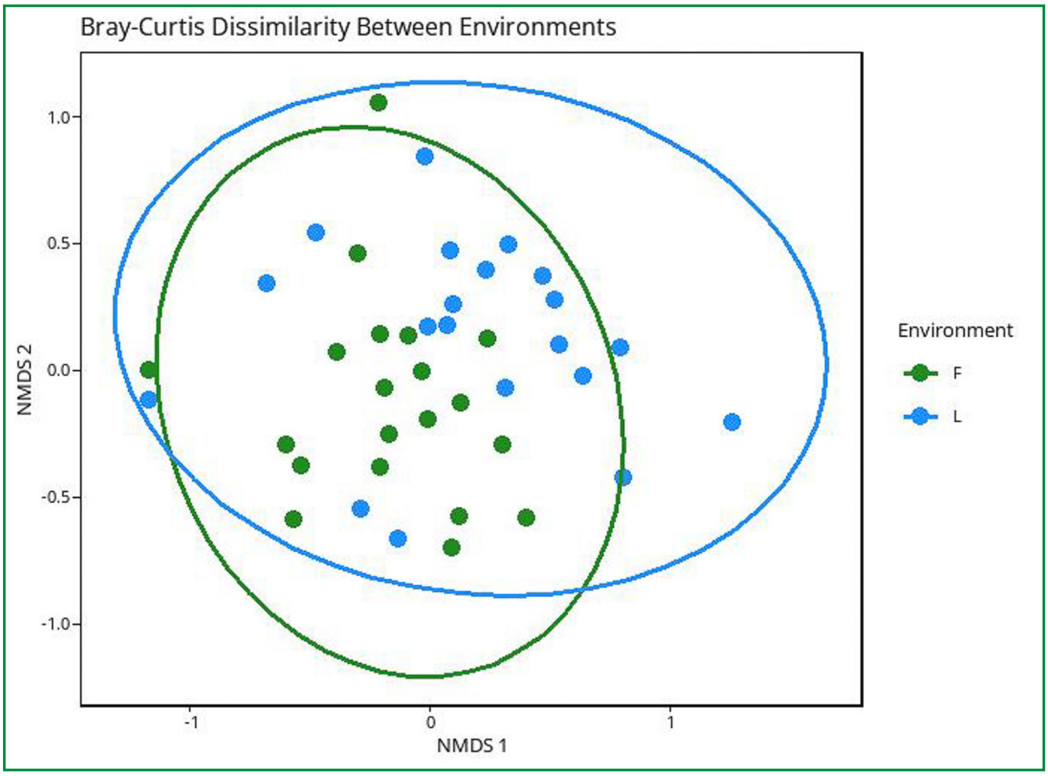
Source: Authors (2025)

Pioneer species (n = 12) were the dominant successional group in both environments. These light-demanding species are typically first to colonize post-disturbance sites and play a key role in facilitating the establishment of shade-tolerant early-secondary species (Baider et al., 1999; de Souza et al. 2006).

In disturbed ecosystems, pioneer species generally decline as succession progresses, particularly short-lived taxa such as *Cecropia* spp. (Puig, 2008). These species rapidly occupy newly formed gaps, especially those smaller than 100 m² and less than three years old (Rivett et al., 2016), thereby contributing to environmental resilience and promoting forest succession after natural or anthropogenic disturbances (Martins et al., 2012).

Bray–Curtis dissimilarity analysis based on absolute species densities revealed partial overlap between undisturbed forest and logging deck sampling points (Figure 7), indicating the presence of shared species between environments. This pattern emphasizes the importance of maintaining surrounding areas within forest management plans, since they contribute to post-disturbance recovery and the persistence of regenerative processes. Conversely, logging deck sampling points located outside the overlap region suggest that logging-related disturbances, such as canopy opening and soil compaction, continue to influence soil seed bank composition, even eight years after harvesting.

Figure 7 – Bray-Curtis floristic dissimilarity of soil seed bank sampling points from logging decks (L) and undisturbed forest (F) in the Jamari National Forest (Flona Jamari), Rondônia, Brazil



Source: Authors (2025)

Araujo et al. (2001) examined soil seed bank density and floristic composition in successional forests of the Lower Guamá River region in the Eastern Amazon. Across three sites representing different stages of post-logging succession (6, 17, and 30 years), similarity indices ranged from 0.61 to 0.68. The authors attributed this similarity to the proximity of intact forest, which facilitates seed dispersal. Accordingly, surrounding forest areas play a crucial role in the recovery of disturbed environments by replenishing species composition and regenerative capacity, while also functioning as indicators of resilience in managed Amazonian forests.

In line with these findings, the species composition and ecological groups recorded in the soil seed bank of logging decks eight years after logging suggest convergence toward undisturbed forest conditions. This pattern indicates ongoing biodiversity recovery at altered sites through the reintroduction of species present prior to harvesting.

4 CONCLUSIONS

The soil seed bank of Annual Production Unit (UPA) 01 showed higher species and family richness in the undisturbed forest environment, with *Bellucia grossularioides* (Melastomataceae) standing out as the most prominent species.

Seedling density and floristic composition did not differ significantly between forest and logging deck environments, highlighting the capacity of Amazon forests to recover following timber extraction.

Finally, the occurrence of timber-value species in the soil seed bank is a valuable indicator of the persistence and maintenance of commercially important species populations in Amazonian forests.

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