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Evaluation of tree and shrub species of natural regeneration in the phytoremediation process of a decommissioned dump in Rio Branco, Acre, Brasil

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ABSTRACT

Phytoremediation is a technique that involves the use of plant species capable of absorbing toxic substances and storing them in their structures. Although promising, there is a lack of studies validating the long-term efficacy of tree species for this purpose. The aim of this study was to identify tree and shrub species with potential for use in the phytoremediation of soils contaminated with heavy metals in a dump decommissioned since 2010 in Rio Branco, Acre. Tree and shrub species with a DBH > 15 cm were selected in a natural regeneration area within the inactivated dump. Chemical analyses of leaves and roots were conducted to determine concentrations of lead, nickel, chromium, copper, and cadmium. Additionally, soil samples were collected to assess nutrient levels and contaminants around the trees. The species *Ceiba pentandra*, *Tectona grandis*, *Leucaena leucocephala*, *Aegiphila* sp., and *Ricinus communis* were identified. *R. communis* and *L. leucocephala* demonstrated superior performance in metal sequestration without showing signs of toxicity. The study shows that certain tree and shrub species exhibit significant potential for use in the phytoremediation of contaminated soils. However, caution is advised regarding the use of exotic and invasive species for the restoration of degraded areas in the Amazon.
Keywords: Phytoextraction. Phytostabilization. Heavy metals.

Avaliação de espécies de árvores e arbustos de regeneração natural no processo de fitorremediação de um lixão desativado de Rio Branco, Acre, Brasil

RESUMO

A fitorremediação é uma técnica que envolve a implementação de espécies vegetais capazes de absorver substâncias tóxicas e armazená-las em suas estruturas. Embora seja promissora, faltam estudos que validem a eficácia a longo prazo de espécies arbóreas para este fim. O objetivo deste estudo foi identificar espécies de árvores e arbustos com potencial para uso na fitorremediação de solos contaminados com metais pesados, em um lixão desativado desde 2010, em Rio Branco, Acre. Foram selecionadas espécies de árvores e arbustos com DAP > 15 cm em uma área de regeneração natural dentro do antigo lixão. Análises químicas de folhas e raízes foram realizadas para determinar as concentrações de chumbo, níquel, cromo, cobre e cádmio. Ademais, amostras de solo foram coletadas para avaliar os níveis de nutrientes e contaminantes ao redor das árvores. As espécies *Ceiba pentandra*, *Tectona grandis*, *Leucaena leucocephala*, *Aegiphila* sp. e *Ricinus communis* foram identificadas. *R. communis* e *L. leucocephala* demonstraram desempenho superior

no sequestro de metais sem apresentar sinais de toxicidade. O estudo demonstra que certas espécies de árvores e arbustos apresentam potencial significativo para uso na fitorremediação de solos contaminados. Todavia, um alerta se faz com relação ao uso de espécies exóticas e invasoras para a recuperação de áreas degradadas na Amazônia.
Palavras-chave: Fitoextração. Fitoestabilização. Metais pesados.

INTRODUCTION

Each passing year, the world generates more solid waste, and most of it is either openly dumped or buried in the ground. According to the International Solid Waste Association (ISWA, 2017), currently, 40% of the solid waste produced worldwide is sent to dumps, which are potentially polluting areas, sources of environmental contamination, and emitters of greenhouse gases. Several scholars agree that dumps are among the most polluted areas globally, and the environmental contamination they cause is a significant global concern (KAZA et al., 2018). According to Silva et al. (2019), there is a substantial commercial and environmental demand for techniques that can minimize or remediate these areas.

Logically, waste generation increases with population growth; however, the unsustainable management of solid waste is directly driven and sustained by increased consumption (MARQUES, 2020). To understand the severe reality of contaminated areas, consider that the 50 largest dumps globally, mapped by ISWA (2017), impact the daily lives of 64 million people, equivalent to the population of France. ISWA states that if current trends continue, dumps will be responsible for 8 to 10% of anthropogenic greenhouse gas emissions by 2025, significantly contributing to climate change.

Addressing the global issue of proper solid waste disposal is crucial for the eradication of poverty, public health and well-being, clean water and sanitation, sustainable consumption and production, sustainable cities and communities, aquatic life, action against global climate change, and terrestrial and aquatic biodiversity. These are among the Sustainable Development Goals defined by the United Nations in the 2030 Agenda for sustainable development (UN, 2015). In this spirit, the United Nations Decade of Ecosystem Restoration (2021-2030) also recognizes that waste and emissions from industry pollute waterways, soil, and air. It sets the goal of preventing, halting, and reversing the degradation of ecosystems on all continents and oceans.

The practice of using dumps is common in developing countries. The region with the worst waste management conditions is Southeast Asia, where low-income countries and vectors of contamination and diseases predominate (ISWA, 2017). Even in tourist areas in tropical regions, environmental contamination results from poor waste management, such as Thilafushi Island in the Maldives archipelago, which is essentially a "garbage island" (PALETTA, 2020). Countries in South and Central America also predominantly dispose of their waste in dumps (ISWA, 2017).

The primary impact of dumps is the threat they pose to aquifers. Leachate, a liquid that percolates through the soil from decomposing waste, can reach and contaminate groundwater (FOSTER; HIRATA, 1991). Being subject to toxic metallic and organic components, such as cadmium (Cd), lead (Pb), arsenic (As), cobalt (Co), copper (Cu), mercury (Hg), nickel (Ni), and zinc (Zn), these contaminants can enter the food chain in high concentrations, posing risks to all living organisms (SILVA et al., 2019; ACHIBA et al., 2009).

Homes adjacent to dumps are often more likely to be affected by diseases that cause neurological damage, anemia, kidney failure, immunosuppression, gastrointestinal and respiratory irritation, skeletal system abnormalities, liver inflammation, liver cancer, and cardiovascular diseases due to chronic exposure to metals such as Pb, Hg, Cd, and As (MAVROPOULOS, 2015).

In Brazil, the National Sanitation Information System (SNIS) estimates that around 56% of cities still send their waste to dumps (SNIS, 2022). Notably, throughout the North region, the largest in territorial terms in Brazil, only 16 sanitary landfills are in operation, compared to 299 dumps (SNIS, 2022). This disparity between the number of landfills and dumps reflects the challenges faced in implementing more sustainable waste management methods in the Amazon region.

Sanitary landfills provide a proper disposal area by systematically distributing waste while adhering to specific operational standards to avoid public health and safety risks and minimize adverse environmental impacts (Brazil, 2010).

Controlled landfills, in terms of suitability, fall somewhere between sanitary landfills and dumps; they often lack proper hydrological conditions and have partial or nonexistent gas and leachate management systems (MAVROPOULOS, 2015). According to Waldman (2013), controlled landfills are a disguised version of dumps, essentially an "improved dump."

Dumps typically lack control or records of waste, which often comes from various sources, includes different types and compositions, and is rarely covered or compacted.

Open burning is also common (ISWA, 2017). In these locations, there may be no, or at most very limited, measures to control operations and protect the surrounding environment (MAVROPOULOS, 2015).

Dumps have been prohibited since Law 2,312 of 1954 (General Health Protection Standards) and reinforced by Law 6,938/1981 (National Environmental Policy - PNMA). However, it was only in 2010, with Law 13,305, that the National Solid Waste Policy (PNRS) established the deadlines and criteria for the closure and remediation of these sites. The management of Contaminated Areas (ACs) also has its own legislation. CONAMA Resolution 420/2009 established criteria for identifying and classifying contaminated areas and prevention values against limits of potentially toxic elements in soil and water.

It is often recommended to redevelop decommissioned dumps as parks, recreational areas, sports fields, and, more recently, greenfields. However, the requalification of these areas requires a series of precautions and specific technical and scientific knowledge throughout the phases of contamination investigation, project development, implementation, and maintenance (Barros, 2011).

For the management of contaminated areas (ACs), CONAMA Resolution 420 of December 28, 2009 brings a series of environmental criteria to be evaluated and establishes guiding values for soil and water quality regarding the presence of toxic substances (Brasil, 2009). In accordance with paragraph V of art. 6th of the aforementioned resolution, environmental contamination is:

> "(...) the presence of chemical substance(s) in the air, water or soil, resulting from human activities, in concentrations such as to restrict the use of this environmental resource for current or intended uses, defined based on assessment risk to human health, as well as to the assets to be protected, in a standardized or specific exposure scenario." (BRASIL, 2009),

Resolution 240/2009 CONAMA also brought the Guiding Values to determine the quality of soil and water, which can be classified as, in accordance with art. 6th:

> "XXII - Quality Reference Value – VRQ is the concentration of a certain substance that defines the natural quality of the soil, being determined based on statistical interpretation of physical-chemical analyzes of samples from different types of soil;
> XXIII - Prevention Value – VP is the limit value concentration of a given substance in the soil, such that it is capable of sustaining its main functions in accordance with art. 3rd; (…)"
> (BRASIL, 2009)

An alternative for decontaminating a dump area is bioremediation, which consists of using living organisms to eliminate or reduce contaminants from soil or water, without causing environmental damage and at relatively low costs that are accessible to Brazilian municipalities (LIMA, 1998; AZEVEDO, 2014; PETERSEN et al., 2023). Among the forms of bioremediation applied are microbial bioremediation and phytoremediation, the first being more efficient for decontaminating the soil with organic substances and the second for inorganic substances (AZEVEDO, 2014).

The phytoremediation technique has been widely implemented in developed countries, where waste is already well managed and the problem of contaminated areas has been resolved (GRATÃO et al., 2005), mainly in countries such as the United States, Canada and Germany due to their great technical and economic viability (SILVA et al., 2019). Contaminated plant parts can be safely harvested and detoxified *ex situ*. To do this, it is necessary to have knowledge of plant species adapted to carry out cleaning efficiently, so that they can be selected to remediate soil or water contaminated by toxic elements (GRATAO et al., 2005).

The technique applies to almost all types of contaminants, including metals, pesticides, solvents, explosives, crude oil and hydrocarbons (SILVA et al., 2019). Among the advantages of using the technique, according to Vasconcellos et al. (2012), is the low cost, possibility of *in situ* application in large areas and for different types of pollutants, as well as easy monitoring of plants, soil maintenance and stimulating the life of organisms, in addition to the possibility of being combined with other decontamination methods.

According to Lamego and Vidal (2007), among the phytoremediation mechanisms carried out by plants, there are phytoextraction, phytodegradation, phytovolatization, phytostabilization and phytostimulation. Phytoextraction occurs through the absorption and translocation (transport) of the metal to aerial organs and storage in, stems, leaves, fruits and seeds. Phytodegradation is indicated for the elimination of organic pollutants through their own enzymatic activities. Phytovolatization is the mechanism in which the plant, when absorbing the contaminant, mostly organic, can volatize it into the atmosphere. Phytostabilization or phytoimmobilization occurs through absorption and immobilization or storage of the contaminant in the root. Phytostimulation occurs due to the presence of microorganisms in the roots which carry out the degradation of contaminants.

To eliminate heavy metals, phytoextraction and phytoimmobilization by plants are often studied, as these metals are chemical elements that cannot be degraded into smaller structures, and it is undesirable for these contaminants to return to the environment through volatilization.

Plant species most suitable for phytoextraction have high translocation factor (TF) values, which refer to the ratio of metal content in the aerial parts of the plant compared to the roots. A high TF indicates that the species is efficient in transporting metals from the roots to the shoots, making them ideal for phytoextraction. In contrast, species recommended for phytoimmobilization should exhibit lower TF values (Machado, 2011). Specifically, species with a TF greater than or equal to one ($TF \geq 1$) are suitable for phytoextraction, while those with a TF less than one ($TF < 1$) have potential for phytoimmobilization (BERNADINO, 2018).

Plants that perform phytoextraction are often associated with accumulator or hyperaccumulator species. These are plants capable of concentrating metals in their above-ground tissues at levels significantly higher than those present in the soil (MALIK; BISWAS, 2012). Hyperaccumulators are particularly valuable for remediating soils contaminated with heavy metals because they can concentrate these metals in their tissues more effectively than other plants (GRATÃO et al., 2005). Phytochemical studies suggest that hyperaccumulation is closely linked to metal tolerance mechanisms, which play a crucial role in the successful colonization of metalliferous and otherwise phytotoxic soils (BAKER; BROOKS, 1989).

The capacity for hyperaccumulation varies depending on the specific metal absorbed. For cadmium (Cd), hyperaccumulators are defined as those that contain more than 0.01% of the metal in the dry weight of their leaves (100 mg kg^{-1}) (BAKER, 1987, cited in CARNEIRO et al., 2002). For nickel (Ni), cobalt (Co), copper (Cu), chromium (Cr), and lead (Pb), hyperaccumulator plants are those that contain more than 0.1% (1000 mg kg^{-1}) of the metal, while for zinc (Zn), hyperaccumulators are those with metal concentrations exceeding 1% (10,000 mg kg^{-1}) in their leaves (BAKER; BROOKS, 1989).

Currently, the majority of the knowledge base on phytoremediation focuses on the application of plant species with an annual life cycle (SILVA et al., 2019). In Brazil, most of the widely used species are exotic, having been introduced and naturalized long ago, and are generally herbaceous. Some of these include *Brassica juncea* (mustard), *Canavalia ensiformis* (jack bean), *Helianthus annuus* (sunflower), and *Zea mays* (corn) (PEREIRA, 2022). However, species of the genus *Brassica*, which are well-known for their hyperaccumulation properties, have demonstrated limitations, such as reduced root length and diminished absorption capacity in the presence of multiple heavy metals in solution (EBB; KOCHIAN, 1997). Studies have shown that plant characteristics that enhance phytoremediation include rapid growth, high biomass production, strong competitiveness, pollution tolerance, high nutrient absorption capacity, high translocation rates, and substantial accumulation of reserve substances (SINGH; JAIN, 2003).

In this context, tree species have generally shown lower signs of toxicity when used in phytoremediation programs (PULFORD, 2003). Additionally, the metals absorbed by these trees remain immobilized in plant tissues for extended periods, thereby delaying the return of these elements to the soil (SOARES et al., 2001). In Brazil, studies on the phytoremediation potential of native species are scarce. Among the native species that have been studied for their phytoextraction potential are the purple ipê (*Tabebuia impetiginosa*), pink cedar (*Cedrela fissilis*), canafistula (*Peltophorum dubium*), embaúba (*Cecropia pachystachya*), angico (*Parapiptadenia rigida*), and timbaúva (*Enterolobium contortisiliquum*) (PEREIRA, 2022).

Although promising, this technique is relatively new, and there is a lack of studies that demonstrate and detail its efficiency in the field, particularly studies proving the potential of native woody species for this purpose. This includes species that have shown potential for the phytoremediation of various contaminants in another research (BRAGA; ZANETI, 2021; PETERSEN et al., 2023). To identify plants with such potential, Sessitch et al. (2013) suggest observing plants that colonize contaminated areas, as these areas may serve as a genetic reservoir of tolerance for use in phytoremediation (BECERRIL et al., 2007).

Given the global solid waste problem, the need for cost-effective alternatives for application across large areas, and the potential of phytoremediation techniques, this study aimed to identify some of the tree and shrub species present at the deactivated dump in Rio Branco, Acre (southwest Amazonian region) to identify native species with potential for use in phytoremediation.

MATERIAL AND METHODS

The study was carried out in the deactivated dump in the municipality of Rio Branco, capital of the state of Acre, Brazil, located at latitude 10°0'55.37” and longitude 67°54'41.71”, along the AC-090 (Transacreana) highway. The dump is located in the São Francisco River basin, close to the peripheral limits of the urban area of Rio Branco (Figure 1).

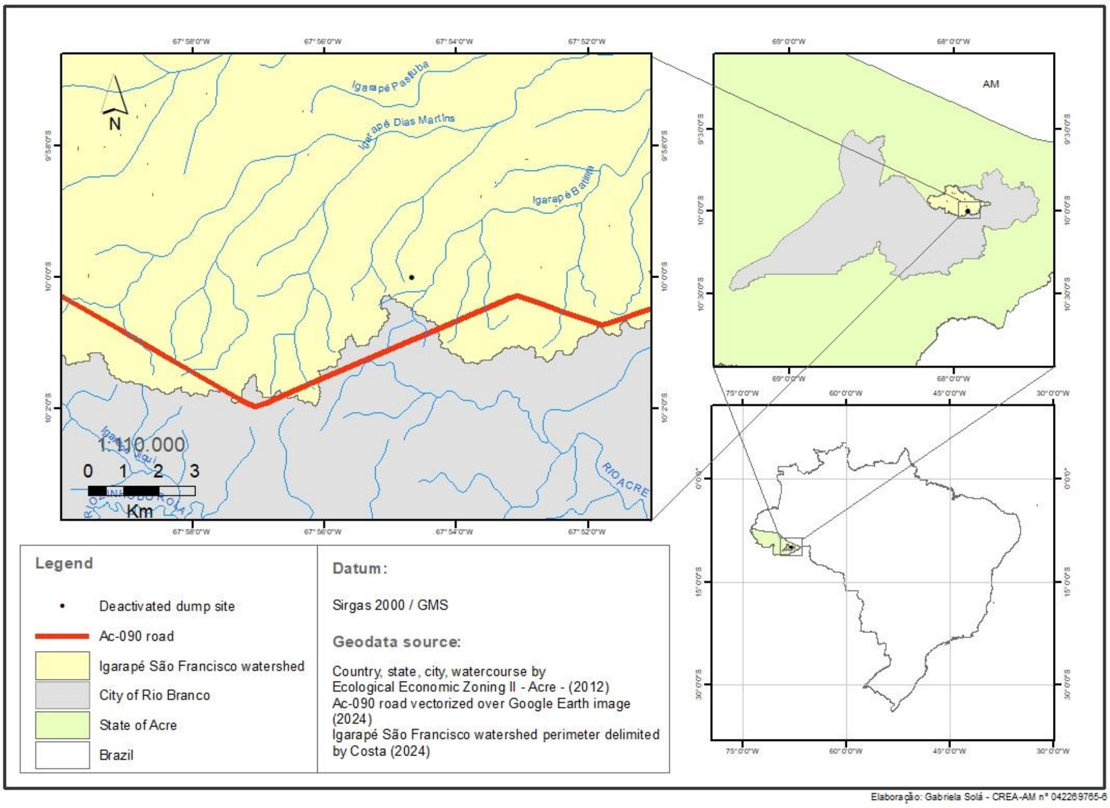
The Rio Branco dump began its activities around 1977, with a total area of 22 hectares, and in 2006 its physical capacity was exhausted due to the long period of use (CPRM, 2006). The waste disposal continued until its deactivation in 2010, when the closure works began (RIO BRANCO, 2010).

During the period of full activity, around 140 tonnes of regular waste, 1.4 tonnes of healthcare waste and around 5 tonnes of waste from pruning and weeding were deposited daily. After the period of activity, the situation in the area remained completely uncharacterized in the landscape, in addition to the predictable change in physical, chemical and biological characteristics due to the impacts resulting from the deposition of waste for a prolonged time (RIO BRANCO, 2010).

The closure and remediation project contracted by Rio Branco City Hall aimed to transform it into a controlled landfill, followed by deactivation. In 2010, the Environmental Recovery Plan for the Controlled Landfill Area of Rio Branco – AC (RIO BRANCO, 2010) was implemented, which led to the gradual closure, until complete closure in 2012, shortly after the inauguration of the Solid Waste Treatment Unit, currently waste receiver in the municipality.

The closure included remediation activities for the area, with the most critical and essential for the landfill being the installation of a gas and leachate drainage system, along with monitoring instruments (RIO BRANCO, 2010).

Figure 1 - Location of the deactivated dump site in Rio Branco, Acre, Brazil.



For remediation purposes, covering with soil with the recommended degree of compaction and revegetation and isolation of the area were carried out, as described in the Environmental Recovery Plan (RIO BRANCO, 2010):

a) Covering and final capping: deposition of soil in layers with a thickness of 40 cm compacted with a degree of compaction with a permeability coefficient k 1 x 10^{-7} cm/s;
b) Revegetation and isolation of the area included the planting of a plant barrier on the boundaries of the land and the implementation of surface protection of the slopes. The revegetation of the site was carried out differently inside and outside the slopes. On the slopes, organic matter was spread and manual weeding was carried out as a complement to the planting of grass. In the project, the grass species is not detailed. On the service and contour roads of the area, due to the greater flow of vehicles, Mangium (*Acacia mangium)* and Leucaena (*Leucaena leucocephala)* were planted as a barrier against dust from truck traffic, and a semi-transparent visual curtain, like an avenue, thus reducing the visual impact, following the outline of the boundary fence of the project area, being planted every 2.00 m away.

Twelve years after the closure and isolation, the area has most of its extension covered by low vegetation, and some formations with palm trees, trees and shrubs. It is also possible to observe the presence of isolated individuals. Most of the area is made up of open fields with grass and herbs, mainly on old slopes and in regions with lower altitudes (171 meters). Vector data from the hydrography delimited by the Ecological Economic Zoning (2012) of Rio Branco was consulted, and it was confirmed that downstream, that is, in the shallow region of the old project, there is the presence of an intermittent water course.

The region's climate is tropical monsoon, Am2, according to the Koppen classification, characterized by rainfall throughout the year and an annual dry period of 3 months. There are two distinct seasons characterized in the region, described as winter and Amazonian summer, where there is much less rainfall in winter than in summer. The municipality receives around 2,022 mm of rain per year, and an average annual temperature of 25.4 °C (SOUSA, 2020). The rainy period occurs between October and May, and the dry period between June and September.

In a smaller part of the areas, mainly on the edge of the old slopes, forest formation is observed in an initial secondary stage of development, located further upstream of the terrain, in the highest region (183 meters in altitude) (Figure 2).

The forest formation, on the edge of the first slope deactivated in 2010, upstream from the periphery of the dump, is composed of trees, shrubs, and an understory with herbs and grasses, in a partially closed canopy stage, formed mainly by the tree canopy of leucaenas, with the presence of a seedling and seed bank.

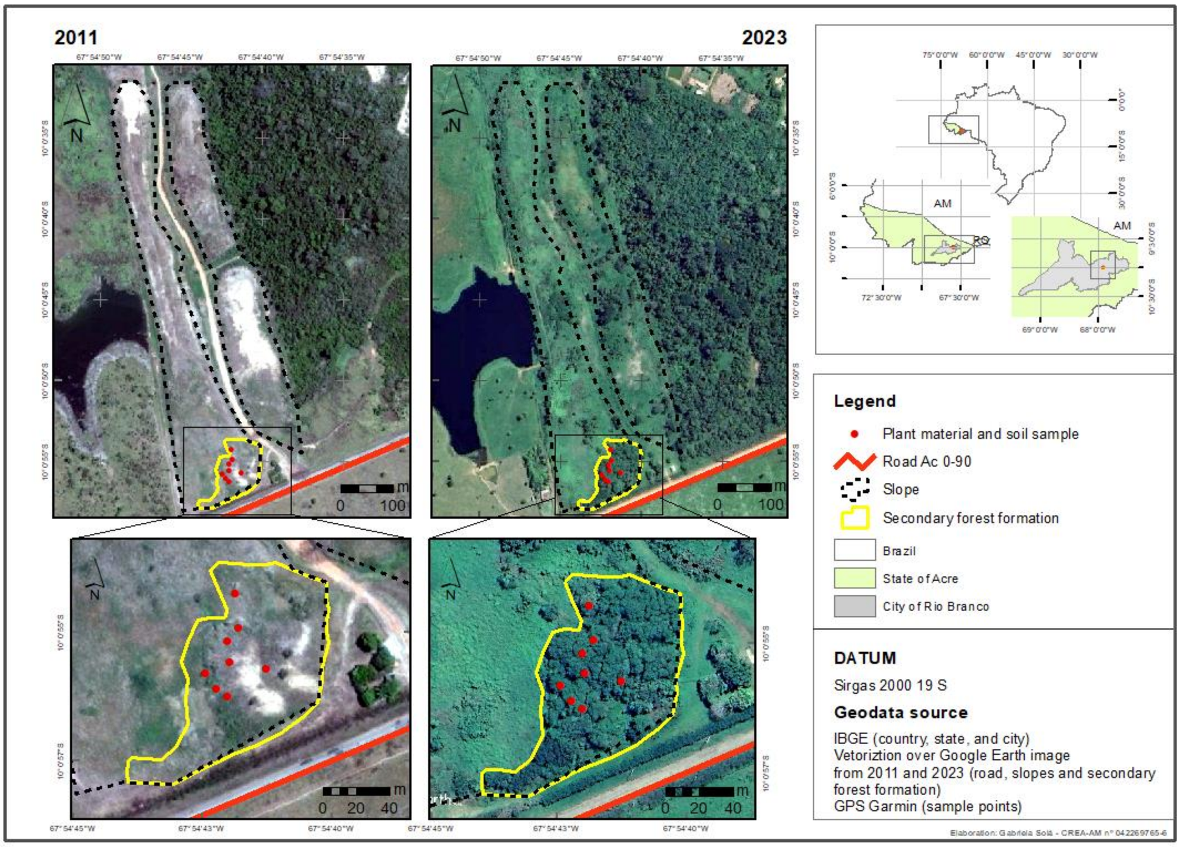
It is estimated that the area began the natural regeneration process in 2011, shortly after the slope was isolated. The area has the highest altitude among all the slopes of the old dump, lower slope and less rugged topography.

On May 17, 2023, in the secondary forest formation resulting from natural regeneration of the old Rio Branco dump, at least 1 and a maximum of 3 individuals of each species were selected, which contained DBH greater than 15 cm for collection of the plant parts that would be analyzed.

Figure 2 - Aerial image of the studied area showing natural regeneration at a decommissioned dump site in Rio Branco, Acre, Brazil. The black rectangle highlights the forest formation where the study was conducted. Photo by Edgard Oliveira.

In addition to quantifying metals, herbarium specimens were prepared to identify some tree species that could not be identified in the field, and the botanical form was completed. Herbarium specimens were prepared following the methodology used at the UFAC Botany Laboratory and the Zoobotanical Park Herbarium. Branches were collected from the trees using a pruning knife and a height extender, along with reproductive material when available. In the field, this material was placed in a press for drying, using newspaper, tied with string, labeled, and then sent to the Herbarium. A field record form, adapted from the model developed by the Brazilian Herbarium Network (2020) was used to record data such as habit, bark texture, leaf type, and fruit type to assist in botanical identification. Biometric measurements were taken for each tree using a tape measure to obtain the circumference at breast height (CBH), which was then used to calculate the diameter at breast height (DBH), while tree height was estimated visually. To assess plant health, leaf color was evaluated, along with the presence of signs of toxicity and disease. Samples were collected in total from 9 individuals, from 5 species, 4 species of trees and 1 species of shrub, for analysis of the quantification of metals in leaves and roots. Soil was also collected around each plant. The location of the individuals selected for collection of botanical material and soil is shown in Figure 3.

Figure 3 - Satellite image from 2011 showing the recently deactivated dump, and from 2023 showing the secondary forest formation in the area, along with the sample collection points. Photo by Gabriela Soares Sola.



For the determination of metals in the plants, branches of mature leaves were collected with a pruning knife while the roots were scraped superficially (1 cm thick) with the aid of a knife. The materials were placed in labeled paper bags. In the laboratory, the material was dried in an air circulation oven at 45 °C for 48 hours. After that, the material was crushed in a domestic food processor to grind it into powder form.

After drying and identifying the powdered leaf and root samples, they were sent to the Brazilian Laboratory of Environmental and Agricultural Analysis (LABRAS) for quantification of the concentration of metals Pb (lead), Ni (nickel), Cr (chromium), Cu (copper) and Cd (cadmium) according to Silva (2020). Readings were carried out using coupled plasma optical emission spectroscopy (ICP-OES) for inorganic contaminants. The technique involves the analysis of light emitted, absorbed or dispersed by atoms, basically being the study between matter and electromagnetic radiation. The principle of the technique involves measuring the radiation emitted when atoms and ions are excited by radiation from a plasma return to the ground state (COLZATO, 2020).

To analyze the tolerance of plants regarding the absorption of metals, the values of metal concentrations in each part of the plant were compared with reference values from the literature that compile concentrations considered toxic for a 10% reduction in growth and critical levels for sensitive plants, prepared by Kabata et al., (2001).

In relation to the plant's ability to phytoextract metals from the soil to the aerial part or phytostabilize the metal in the roots, the translocation factor was analyzed and compared with existing studies in the literature on this trend. It was considered that with FT $\geq$ 1 the plant tends to phytoextract, while FT $<$ 1 has the capacity for phytostabilization.

The translocation factor is mobilization ratio, evaluated to determine the relative translocation of metals from the underground root to the aerial part of the plant species according to the following equation (GUPTA et al., 2008; BARMAN et al., 2000):

$$TF = \frac{Cp}{Cr}$$

Where:

TF = translocation factor;

Cp = metal concentration in the aerial part of the plant (mg/kg)

Cr = metal concentration in the plant root (mg/kg)

The soil from the base of each plant was collected in 5 multiple samples around the plant, at a depth of 0 to 20 cm, with the aid of a stainless auger. The soil samples from each tree were mixed in a bucket, and from the mixture, a composite soil sample was extracted from each plant, constituting a collection point, following the guidelines in the Manual for Collection and Samples Procedures in Agricultural Areas for Environmental Quality Analysis: Soil, Water and Sediments from Embrapa (2006).

In the laboratory, the samples were crumbled and air-dried at room temperature. Once dried and identified, composite soil samples of approximately 500 g were collected from around each tree and sent to the LABRAS Laboratory for physicochemical analysis and metal concentration assessment (Pb, Ni, Cr, Cu, and Cd). The analysis, including pH parameters, macronutrients, micronutrients, and contaminant determination, was conducted following the methodologies developed by Mehlich (1984) and EPA (1996). The obtained metal concentrations were then compared with the preventions and quality reference values established by CONAMA Resolution 420/2009 using the summarized Table 1.

Table 1 - Guiding values for soil (mg kg^{-1}).

METALS	Prevention Values	Quality Reference
Cadmium (Cd)	1.3	0.5
Lead (Pb)	72	13
Copper (Cu)	60	5
Chromium (Cr)	75	35
Nickel (Ni)	30	9

Source: CONAMA, 2009. Adapted by the authors.

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RESULTS AND DISCUSSION

The deactivated dump site in Rio Branco, Acre, Brazil, has been isolated for at least 12 years, undergoing a natural regeneration process. Some areas of the former site are in a more advanced stage of regeneration, as indicated by the formation of small nuclei of early secondary forest, while other areas still feature exposed soil and predominantly low vegetation. These differences may be attributed to the topography of each region and the varying amounts of buried waste.

The forest formation at the collection site comprises vegetation with well-defined lower, intermediate, and upper layers. The identified species are listed in Table 2. The lower stratum is characterized by a marked presence of grasses and herbs that form the undergrowth. The intermediate, denser layer is abundant with Euphorbiaceae, particularly the shrub *Ricinus communis* (castor bean). The upper stratum features a partially closed canopy formed mainly by the crowns of *Leucaena leucocephala* (leucaena) trees.

Table 2 - List of species, botanical data and biometrics. N: number of collected individuals; H (m): maximum estimated height found in meters; DBH (cm): maximum diameter at breast height found in cm.

Common name	Scientific name	Family	N	H (m)	DBH (cm)
Leucaena	*Leucaena leucocephala*	Fabaceae	3	12.3	30.4
Clog tree	*Aegiphila sp.*	Lamiaceae	1	10	20.69

Teak	*Tectona grandis*	Lamiaceae	1	15	58.41
Samaúma	*Ceiba pentandra*	Malvaceae	1	10	21.65
Castor bean	*Ricinus communis*	Euphorbiaceae	2	4.25	19.1

Of the five species identified, three are exotic to Brazilian flora, *Ricinus communis* (castor bean), *Leucaena leucocephala* (leucaena), and *Tectona grandis* (teak), while two, *Ceiba pentandra* (samaúma) and *Aegiphila* sp. are native to the Amazon. In total, four tree species and one shrub species were found, with the most common being *Ricinus communis* and *Leucaena leucocephala*.

Aegiphila sp. and *Tectona grandis* belong to the Lamiaceae family, while the other species belong to the Fabaceae (*Leucaena leucocephala*), Malvaceae (*Ceiba pentandra*) and Euphorbiaceae (*Ricinus communis*) families.

The quantification of metals in the soil around each tree is listed in Table 3. All values were within the limits of the Prevention Value (PV) established by CONAMA Resolution 420/2009.

Table 3 - Concentration of metals in the soil around each tree.

Soil sample around:	**Metals (mg dm^{-3})**				
	Ni	Cd	Cr	Pb	Cu
Leucaena leucocephala (1)	0.71	0.12	0.03	0.55	1.6
Leucaena leucocephala (2)	0.97	0.14	0.05	0.9	1.1
Riccinus common (1)	0.64	0.11	0.03	0.78	1.3
Riccinus common (2)	1.3	0.14	0.03	1.42	1
Tectone grandis	0.81	0.11	0.03	0.91	0.9
Aegiphila sp.	1.1	0.15	0.01	0.51	1.6
Ceiba pentandra	1.04	0.14	0.02	0.5	1.6
Prevention value (PV)*	30	1.3	75	72	60

* According to Resolution 420/2009.

Table 4 describes some attributes of the physical-chemical analysis of the soil. Predominantly the pH of the soil around the trees was considered acidic for *Leucaena leucocephala*, *Ricinus communis*, *Aegiphila sp* and *Ceiba pentandra*, except for *Tectona* *grandis* what presented pH 7 (neutral). The *Riccinus* species *common* obtained a low organic matter content (2.8 dac kg^{-1}) and clayey soil. Teak differed from the others by presenting the highest OM value with a content of 6.1 dac kg^{-1} and sandy - clayey soil.

Table 4 - Soil physicochemical attributes.

Soil sample around:	**pH $CaCl_2$**	**OM (dac kg^{-1})**	**Texture**
Leucaena leucocephala (1)	5	3.6	Clayey
Leucaena leucocephala (2)	5.2	3.8	Clayey
Riccinus communis (1)	5.2	2.8	Clayey
Riccinus communis (2)	5.1	3.8	Clayey
Tectona grandis	7	6.1	Clay-sandy
Aegiphila sp.	5.3	4.1	Clayey
Ceiba pentandra	5.2	3.4	Clayey

The presence of decomposing organic matter in the surface layer, along with occasional debris such as iron objects, tarpaulins, and plastic items discarded on-site, was also observed (Figure 4), while the maximum metal concentrations in the roots and leaves of the evaluated species (Figures 5 and 6) indicated that the plants interacted with the metals in different ways, exhibiting significant variation among them.

In most cases, the metal concentrations in the plants were higher than those in the surface layer of the soil, suggesting metal accumulation over time and/or uptake from deeper soil layers through root growth. This is likely because, during the landfill closure project, a 40 cm layer of soil was deposited over the waste layer.

Figure 4 - Outcrop of solid waste near trees. A) and B) aluminum and scrap metal; C) plastic and iron and; D) and E) plastic.

Figure 4 shows that chromium was, respectively, more accumulated in the roots of *Ricinus communis* (139.47 mg kg^{-1}) > *Leucaena leucocephala* (9.33 mg kg^{-1}) > *Ceiba pentandra* (7.57 mg kg^{-1}) > *Aegiphila sp.* (4.73 mg kg^{-1}); the most accumulated nickel in the roots of *Ricinus communis* (82.68 mg kg^{-1}) > *Aegiphila sp.* (10.23 mg kg^{-1}) > *Ceiba pentandra* (9.15 mg kg^{-1}) > *Leucaena leucocephala* (8.35 mg kg^{-1}); the most accumulated lead in the roots of *Leucaena leucocephala* (24.78 mg kg^{-1}) > *Aegiphila sp.* (0.43 mg kg^{-1}) > *Ricinus communis* (0.08 mg kg^{-1}) > *Ceiba pentandra* (0.07 mg kg^{-1}); the most accumulated cadmium in the roots of *Leucaena leucocephala* (2.29 mg kg^{-1}) > *Ricinus communis* (1.36 mg kg^{-1}) > *Aegiphila sp.* (0.18 mg kg^{-1}) > *Ceiba pentandra* (0.06 mg kg^{-1}); and the copper most accumulated in the roots of *Ricinus communis* (23.89 mg kg^{-1}) > *Aegiphila* sp. (7.39 mg kg^{-1}) > *Ceiba pentandra* (2.07 mg kg^{-1}) > *Leucaena leucocephala* (0.86 mg kg^{-1}). We noted that *Ricinus communis* stands out for the accumulation of chromium and nickel, while *Leucaena leucocephala* stands out for the accumulation of lead and cadmium in the roots.

Likewise, figure 5 shows that chromium was, respectively, more accumulated in the leaves of *Ceiba pentandra* (0.86 mg kg^{-1}) > *Leucaena leucocephala* (10.19 mg kg^{-1}) > *Ricinus communis* (7.59 mg kg^{-1}) > *Aegiphila sp.* (4.22 mg kg^{-1}) > *Tectona grandis* (2.85 mg kg^{-1}) ; the most accumulated nickel in the leaves of *Aegiphila* sp. (26.32 mg kg

$^{-1}$) > *Leucaena leucocephala* (13.39 mg kg^{-1}) > *Ceiba pentandra* (8.09 mg kg^{-1}) > *Ricinus communis* (3.44 mg kg^{-1}) > *Tectona grandis* (0.17 mg kg^{-1})*;* lead most accumulated in *Ricinus leaves communis* (20.19 mg kg^{-1}) > *Aegiphila sp.* (5.01 mg kg^{-1}) > *Tectona grandis* (0.27 mg kg^{-1}) > *Leucaena leucocephala* (0.09 mg kg^{-1}) > *Ceiba pentandra* (0.05 mg kg^{-1})*;* the cadmium most accumulated in the leaves of *Tectona grandis* (2.56 mg kg^{-1}) > *Ceiba pentandra* (0.86 mg kg^{-1}) > *Leucaena leucocephala* (0.52 mg kg^{-1}) > *Aegiphila sp.* (0.23 mg kg^{-1}) > *Ricinus communis* (0.07 mg kg^{-1})*;* copper was more accumulated in leaves of *Aegiphila sp.* (11.86 mg kg^{-1}) > *Leucaena leucocephala* (8.1 mg kg^{-1}) > *Tectona grandis* (7.59 mg kg^{-1}) > *Ricinus communis* (6.65 mg kg^{-1}) > *Ceiba pentandra* (2.57 mg kg^{-1}). We noted that *Aegiphila sp*. stands out for the accumulation of nickel and copper, *R. communis* for the accumulation of lead, *Ceiba pentandra* for the accumulation of chromium and *Tectona grandis* by the accumulation of cadmium in the leaves.

Chromium was the most absorbed metal by the plants, while cadmium was the least absorbed. The lowest metal concentration was 0.05 mg kg^{-1} of Pb in the leaves of *C. pentandra* and *L. leucocephala*, whereas the highest concentration was 139.47 mg kg^{-1} of Cr in *Ricinus communis*. Chromium was absorbed in toxic concentrations by all species in both leaves and roots. *Ricinus communis* exhibited the highest absorption of toxic metal levels in its roots, while *Aegiphila* sp. absorbed the highest toxic levels in its leaves. *Tectona grandis* absorbed the lowest toxic metal levels in its leaves.

In this study, all analyzed species exceeded the upper limits of Cr tolerance reported for sensitive plants, indicating that *Ricinus communis*, *Aegiphila* sp., *Tectona grandis*, *Leucaena leucocephala*, and *Ceiba pentandra* tolerated levels considered toxic to sensitive species and other plants. *Leucaena leucocephala* and *Ceiba pentandra* showed the highest concentrations of Cr in their leaves, with levels capable of reducing plant growth by 10%. *Ricinus communis* exhibited Cr levels in the roots ten times higher than the toxic range reported for several species, suggesting that this species has developed mechanisms for metal tolerance.

Figure 5 - Maximum concentration of metals found in the roots*. Observation: It was not possible to collect *Tectona grandis* root for analysis.

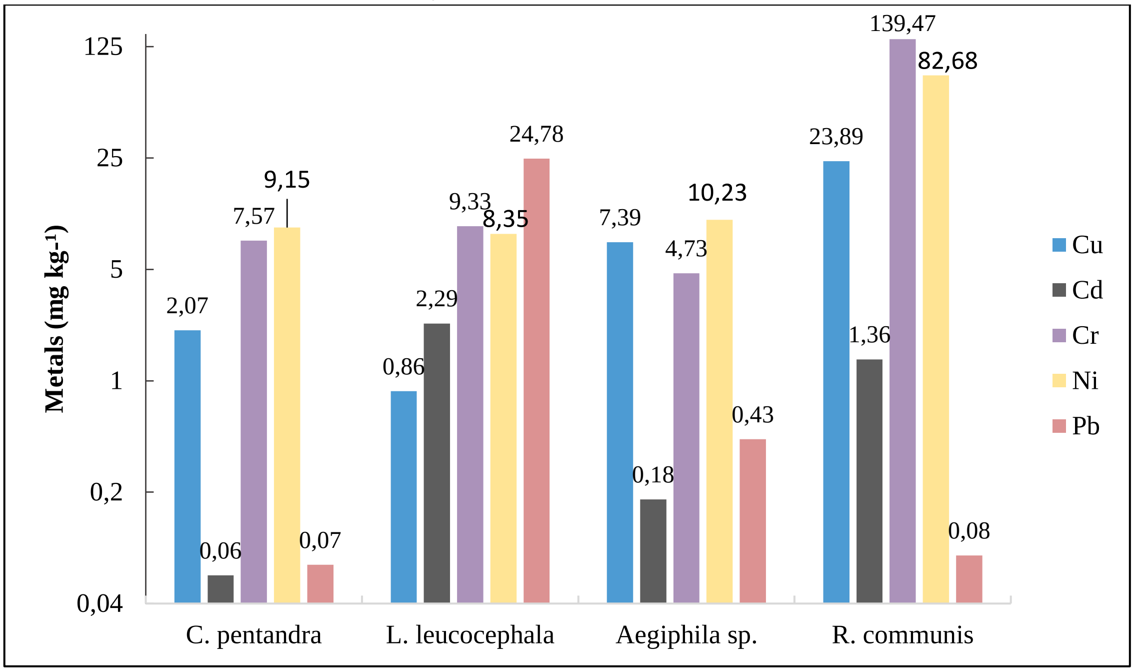
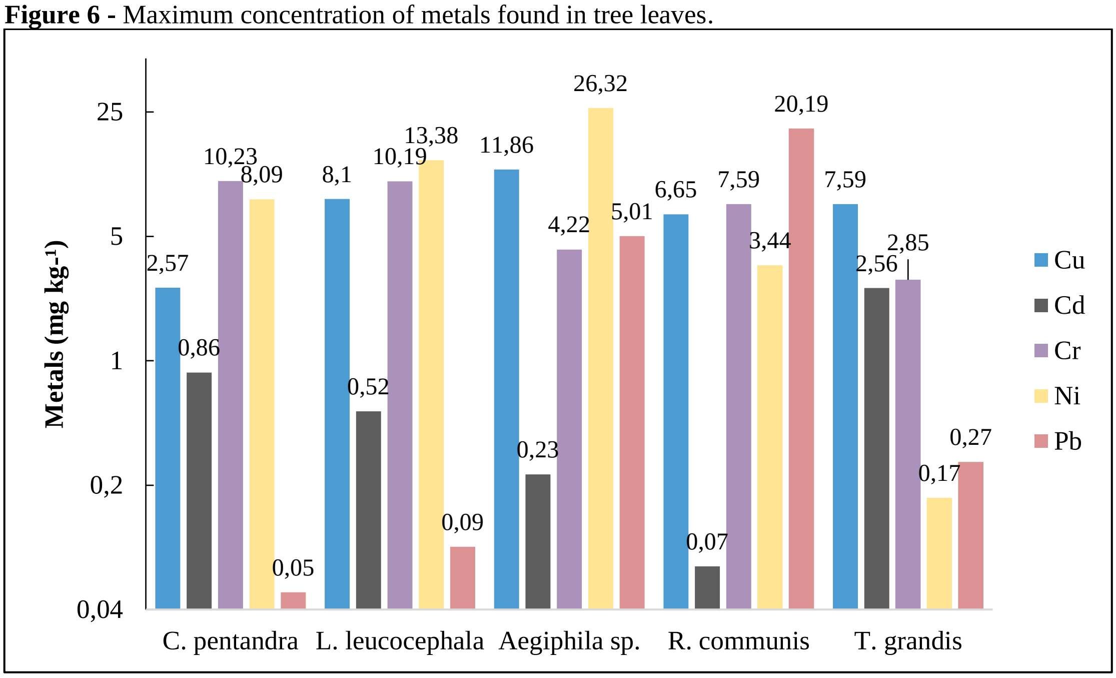
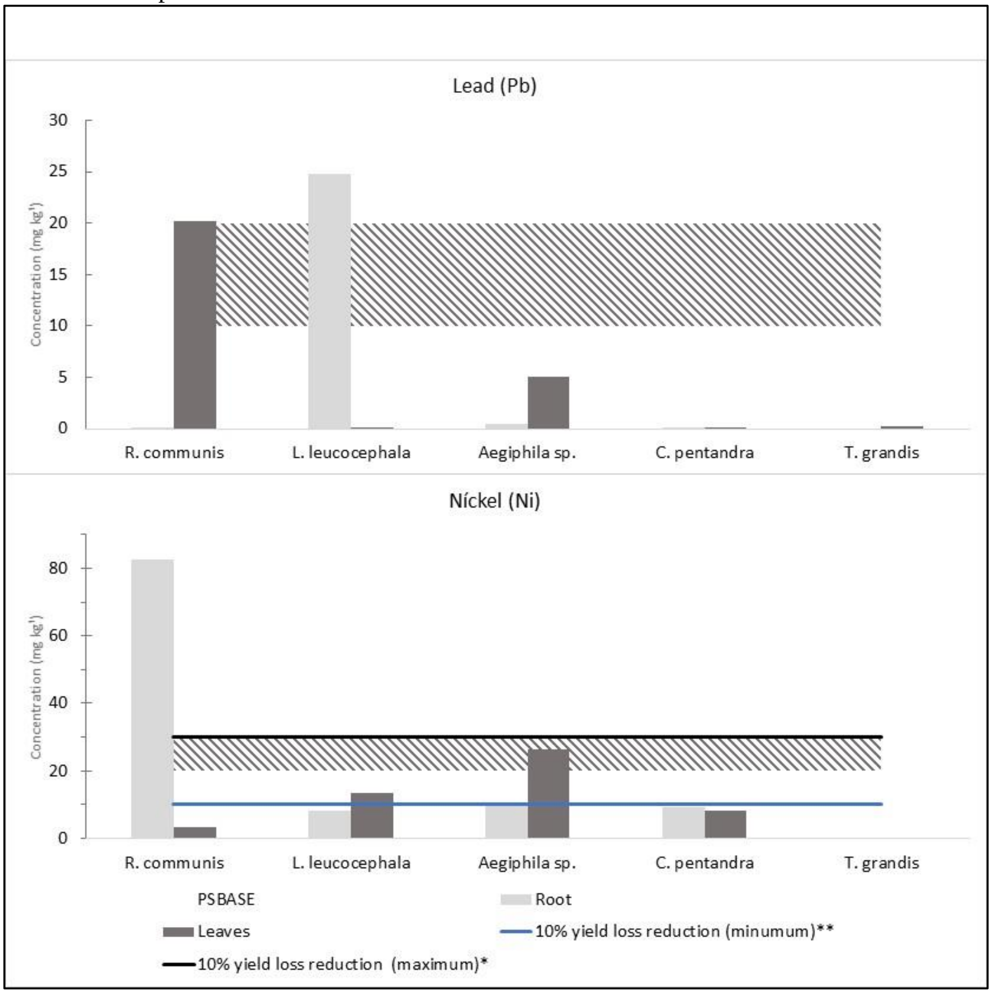


Figure 6 - Maximum concentration of metals found in tree leaves.



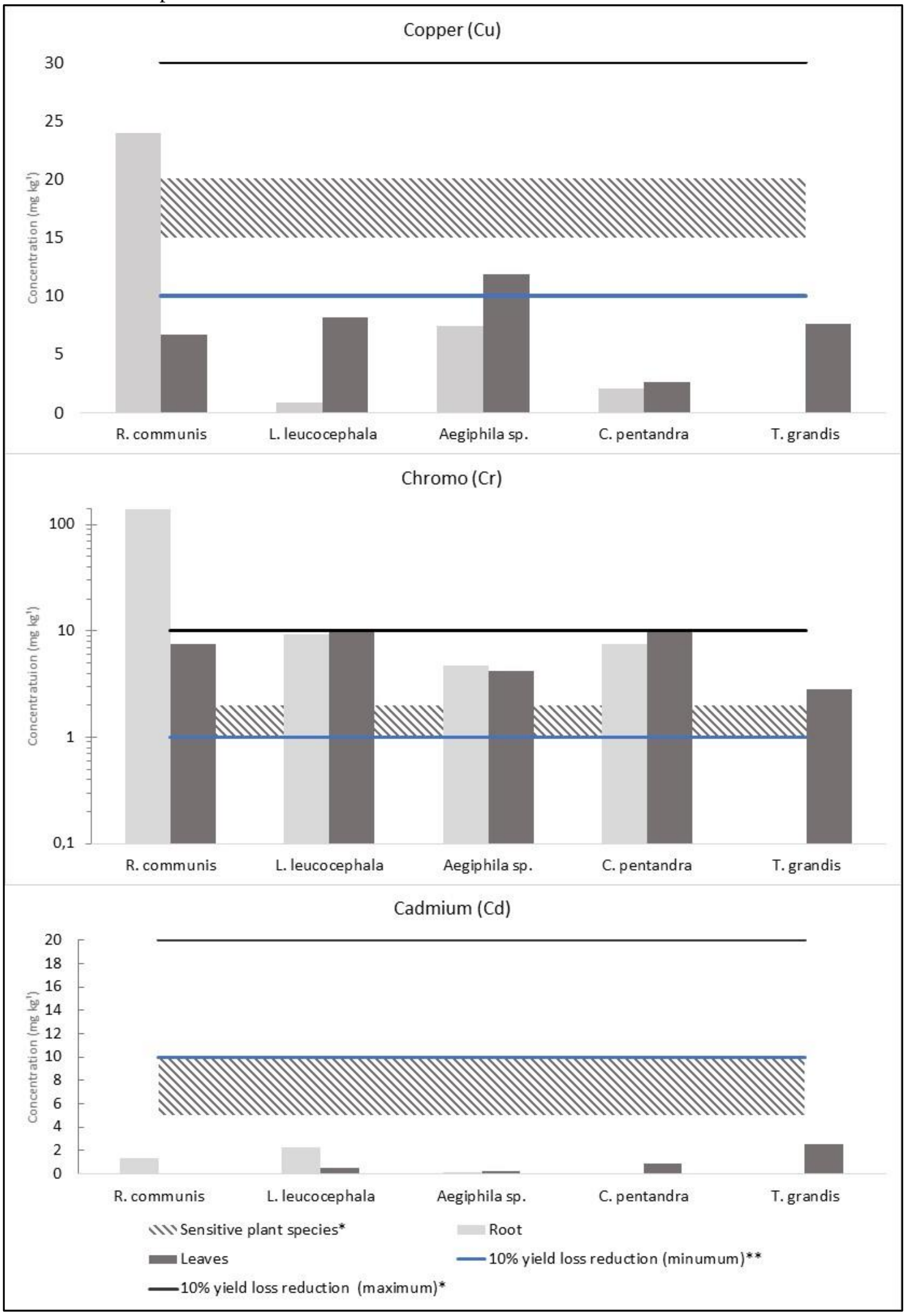
To assess tolerance, the metal concentrations in each part of the plant were compared with reference values from the literature, which compile concentrations considered toxic for a 10% reduction in growth and critical levels for sensitive plants, as outlined by Kabata et al., (2001). This comparison, along with the toxicity thresholds for the metals, is shown in Figures 7 and 8.

Figure 7 - Concentrations of Pb and Ni observed in the studied species and respective critical concentrations (mg kg^{-1}) for 10% yield reduction *minimum levels and **maximum levels according to literature (Kabata et al., 2001). The hatched area indicates concentrations found for sensitive plants.



The toxic metal concentrations found in *R. communis*, in decreasing order, were Cr > Ni > Cu in the roots, and Pb > Cr in the leaves. In *Leucaena leucocephala*, they were Pb > Cr in the roots, and Ni > Cr in the leaves. In *Aegiphila* sp., only Cr reached toxic concentrations in the roots, while in the leaves, Ni > Cu > Cr exceeded toxicity limits. For *Ceiba pentandra*, only Cr reached toxic concentrations in both roots and leaves. In *Tectona grandis*, toxic levels of Cr were found exclusively in the leaves (Figure 8).

Figure 8 - Concentrations of Cu, Cr and Cd found in the studied species and respective critical concentrations (mg kg^{-1}) for 10% yield reduction *minimum levels and **maximum levels according to literature (Kabata et al., 2001). The hatched area indicates concentrations found for sensitive plants.



In terms of the plants' physical health in the field, *R. communis* and *L. leucocephala* did not display any visible signs of toxicity (Figures 9 and 10).

Figure 9 – *Ricinus communis* observed in the deactivated dump. A) Aspect of leaves. B) Aspect of stem.

Figure 10 – *Leucaena leucocephala* observed in the deactivated dump. A) and B) General aspects of the trees. C) Leaves.

C. pentandra exhibited dark green leaves, a thin crown, and signs of pathogen activity (Figure 11). *Aegiphila sp*. displayed obvious signs of poor health, especially evident in the canopy condition (Figure 12). *T. grandis* had an above-average DBH, but with numerous thick branches and a low crown, indicating potential challenges in deep root growth, along with signs of chlorosis (Figure 13).

Figure 11 – *Ceiba pentandra* observed in the deactivated dump. A) and B) General aspects of the tress. C) Stem. D) Leaves.

Figure 12 – *Aegiphila sp.* observed in the deactivated dump. A) Signs of illness. B) Detail of canopy.

Figure 13 – *Tectona grandis* observed in the deactivated dump. A) Leaves with chlorosis. B) Stem bifurcation.

To determine mechanisms of phytoextraction and phytostabilization, we calculated the Translocation Factor (TF) that consists of the relationship between the metal present in the leaves and the roots, demonstrating the relative amount of metal in the leaves. Based on this factor, it is possible to distinguish the physiological mechanisms that occur in the plant from metal absorption and accumulation in the root or translocation to the shoot. Therefore, it can be classified as a phytostabilizer or phytoextractor. Figure 14 contains the concentration of metals in the leaves and roots of each species, and their respective TF.

Table 5 indicates the potential of the species according to the classification of Machado (2011) and Bernardino (2018), which classify the species according to the TF. Where TF ≥ 1 indicates that the plant carried out the process of phytoextraction of the element from the soil, and TF < 1 indicates phytostabilization or phytoimmobilization of the metal in the root.

From this results, we observed that *Ceiba pentandra* acts as a phytoextractor of Cu, Cd, and Cr, and a phytostabilizer of Ni and Pb; *Leucaena leucocephala* functions as a phytoextractor of Cu, Cr, and Ni, and a phytostabilizer of Cd and Pb; *Aegiphila* sp. serves as a phytoextractor of Cu, Cd, Ni, and Pb, and a phytostabilizer of Cr; while *Ricinus communis* operates as a Pb phytoextractor and a phytostabilizer of Cu, Cd, Cr, and Ni (Table 5).

Figure 14 - concentration of metals in the roots, leaves and the translocation factors (TF). TF values are indicated with red triangles. Orange bars represent the concentration of the metal in the roots. Green bars represent the metal concentration in the leaves.

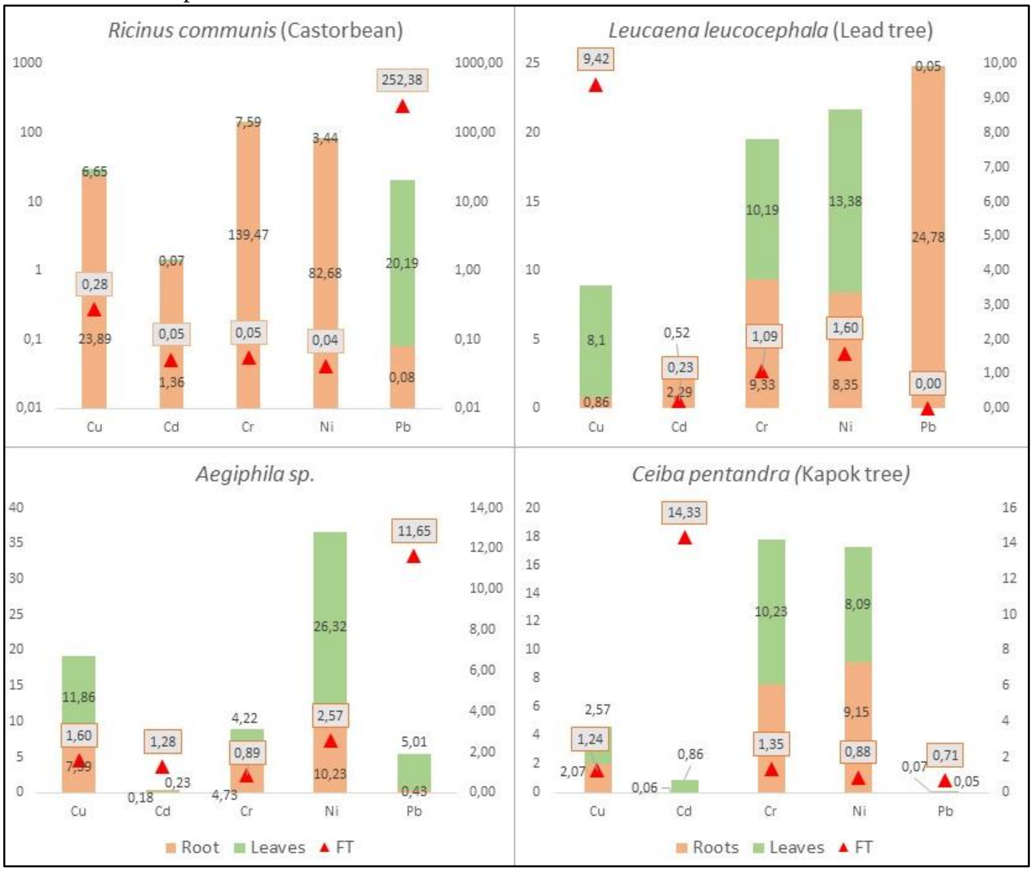


Table 5 - Plant potential for phytoextraction (PE) and phytostabilization (PS).

	Cu	Cd	Cr	Ni	Pb
C. pentandra	PE	PE	PE	PS	PS
L. leucocephala	PE	PS	PE	PE	PS
Aegiphila sp.	PE	PE	PS	PE	PE
R. communis	PS	PS	PS	PS	PE

Native tree species showed translocation factors (TF) greater than 1 for three of the five metals analyzed: *Aegiphila sp*. for cadmium, lead, and nickel, and *Ceiba pentandra* for cadmium, chromium, and copper. Additionally, these species exhibited the second and third highest translocation factors, surpassed only by *Ricinus communis*.

The TF value represents the ratio of metal concentration in the leaves to that in the roots, indicating how many times more metal is present in the leaves compared to the roots. In this analysis, it was found that some species translocated more than twice the metal concentration from the roots to the leaves. The species with the highest metal translocation to the aerial parts were *R. communis* for Pb (TF=252) and *Aegiphila* sp. for Pb (TF=11.65), *Aegiphila sp*. for Ni (TF=2.57), *C. pentandra* for Cd (TF=14.33), and *Leucaena leucocephala* for Cu (TF=9.42).

In general, despite the low bioavailability of metals in the soil surface—characterized by low organic matter, neutral pH, and a clayey texture—*Ricinus communis* absorbed high concentrations of nearly all metals, except cadmium, which none of the species absorbed in significant amounts. The phytoextraction potential of castor beans is especially notable for Pb, where it outperformed the other species. As shown in Figure 13, all other species exhibited translocation factors close to zero, indicating metal immobilization in the roots, except for *R. communis*. Despite the high concentration of lead in its leaves, the species did not show visible signs of toxicity.

In this study, the mature *Aegiphila sp*. tree demonstrated a high capacity to tolerate and/or phytoextract all tested metals. Toxic concentrations of Ni and Cu were supported in the leaves, and the plant also showed a strong ability to phytoextract these metals into its aerial parts. Although Pb did not reach toxic levels, the plant accumulated 12 times more lead in its aerial parts compared to its roots, representing the second-highest translocation factor for Pb observed in the study. For Cd, despite low concentrations, the species had a TF greater than 1, indicating its capacity to phytoextract the metal. Regarding Cr, the plant exhibited both tolerance and phytostabilization capacity, while also accumulating high concentrations of Cr in its aerial parts.

Ceiba pentandra displayed high tolerance to Cr and a significant potential for Cd translocation to its aerial parts. However, the plant showed poor overall development, as evidenced by signs of pathogen presence on the leaves and a sparse crown. Additionally, its proximity to a *Leucaena* tree in the field likely resulted in nutrient competition, further contributing to the suboptimal growth of *C. pentandra*.

Concerning the presence of metals in the soil of the studied forestry region, the elemental content falls below levels deemed harmful to the environment, according to CONAMA Resolution 420/2009. Regarding forest composition, the area was largely colonized by *Leucaena leucocephala* and *Ricinus communis*, both exotic species. Similar findings in terms of soil contamination were reported by Melo Júnior et al. (2015) in a landfill from a coastal municipality in southern Brazil, where a decommissioned landfill site showed low and acceptable metal levels for Brazilian soils. However, in contrast to our study, their floristic composition only included herbaceous plants and shrubs, likely due to the subtropical climate of that region, as opposed to the tropical climate of our site.

It appears to be common for such areas to be initially colonized by exotic species, which some authors classify as invasive (MAMEDES et al., 2017). Castro-Díez et al. (2004) attribute the success of invasive species to the lack of predators, parasites, or diseases in the invaded ecosystems that could limit their spread. This is reflected in our results, where *R. communis* and *L. leucocephala* exhibited the best performance in terms of plant health and metal absorption. While most exotic species coexist with native ones, some can pose a threat to forest biodiversity (SANTOS; CALAFATE, 2018).

The levels of metals in the roots and leaves of these species were several times higher than the concentrations in the soil. According to Siegel (2002), plants can absorb chemical elements proportional to the soil content or even bioaccumulate elements at concentrations that exceed those in the soil. This indicates that all evaluated individuals bioaccumulated the elements.

R. communis was the most abundant species and accumulated the largest amounts of metals. It is often found dominating dump sites and deactivated landfills (PEREIRA et al., 2013; MELO JÚNIOR et al., 2015; MAMEDES et al., 2017). Chromium was the most absorbed element, with a concentration of 139.47 mg kg^{-1} in the roots of *R. communis*, indicating a high tolerance and a phytostabilization mechanism. This significant concentration suggests the species may hyperaccumulate chromium and possibly express a resistance gene. Pereira et al. (2013) also found that *R. communis* tends to immobilize chromium in the roots rather than translocating it to the aerial parts. Furthermore, research on areas contaminated by tannery waste indicates that chromium levels in the aerial parts of plants did not reach contamination thresholds, allowing the plants to still be used for biodiesel production (QUADRO et al., 2019).

Conversely, a study in Pakistan, where *R. communis* is native, found no absorption of chromium in steel-contaminated soils, suggesting that the species may exhibit better metal absorption potential outside its native range (Khan et al., 2024). Regarding nickel, *R. communis* accumulated the metal in its roots, with concentrations three times higher than the toxic range for most species. Giordani et al. (2005) also observed that *R. communis* tends to store nickel more in the roots than in the shoots. Sun et al. (2018) found that organic matter in the soil improved plant growth and metal bioaccumulation, which could explain the species' successful development in our field and its enhanced metal absorption.

Regarding lead, *R. communis* acted as a phytoextractor, translocating about 250 times more lead to the aerial parts than was present in the roots, without exhibiting phytotoxic effects. Lima (2010) also observed this phytoextraction mechanism in *R. communis* when grown in sandy, low-fertility soil with industrial effluent. Similarly, Romeiro (2005) found that *R. communis* plants were potential lead hyperaccumulators in hydroponic cultivation. However, Santos et al., (2012) reported that *R. communis* tended to accumulate lead in its roots under favorable soil conditions, indicating that the phytostabilization mechanism might occur under specific environmental conditions.

For copper, *R. communis* displayed phytostabilization and accumulated concentrations in the roots capable of reducing plant yield by 10%. Andreazza and Camargo (2008) reported that *R. communis* hyperaccumulates copper in vineyard soils, but in mining waste areas with higher copper concentrations, accumulation was about 50% lower. The species' ability to either phytoextract or phytostabilize copper appears to depend on soil concentration.

The study area was predominantly colonized by *L. leucocephala*. The individuals exhibited good phytosanitary and biometric quality, with their canopies dominating the forest cover. *L. leucocephala* is a highly aggressive invasive species (Castro et al., 2017) with autochoric seed dispersal (COSTA; DURIGAN, 2010). Notably, the dump edge was isolated using planted leucaena trees. Despite being native to Mexico, *L. leucocephala* has been reported to colonize areas in China with lead and zinc residues (MA et al., 2003). Among the species studied, *L. leucocephala* absorbed the highest concentration of lead (24.78 mg kg^{-1}), immobilizing it in the roots. This concentration exceeded levels known to reduce the dry weight of seedlings in controlled experiments (Shafiq et al., 2008). However, Bourlegat (2007) found that during initial development, *L. leucocephala* seedlings are not resistant to high lead concentrations, contrasting with the tolerance observed in mature individuals in our study. This suggests that *L. leucocephala* may have developed adaptations to the contaminated environment, a topic that warrants further investigation in future studies.

For chromium, *L. leucocephala* demonstrated potential for phytoextraction, with a maximum concentration of 10.19 mg kg^{-1} in the leaves. Shanker et al., (2005) found that *L. leucocephala* seedlings tend to accumulate chromium in the roots rather than in the shoots, suggesting that the difference in phytoremediation mechanisms may be age-related. Similar chromium levels were also reported by França et al., (2017) in *L. leucocephala* leaves during the dry season.

L. leucocephala accumulated 2.29 mg kg^{-1} of cadmium in its roots, suggesting potential for phytostabilization. González-Velázquez et al., (2022) observed that *L. leucocephala* stores cadmium in the roots at lower concentrations and in the shoots at higher levels. Additionally, the species exhibited a high translocation factor for copper to the aerial parts, making it a strong candidate for phytoextraction, as Oliveira (2018) demonstrated in copper mining waste areas. However, the critical question remains: Do we want to restore areas in the Amazon using exotic species like *Leucaena*?

Tectona grandis, or teak, another exotic species, was found in the study area in good phytosanitary and biometric condition, with the largest diameter among all individuals. However, only one specimen was present. Native to South and Southeast Asia, teak is widely cultivated for its valuable timber (ZUMAETA et al., 2010). In this study, teak accumulated copper, chromium, and cadmium, with chromium levels in the leaves reaching toxic thresholds, yet without affecting canopy health. Research by Erakhrumen and Inaede (2018) and Shanker et al. (2005) suggests that teak is capable of phytoextracting copper and chromium, although no significant bioaccumulation was observed.

Teak's capacity to accumulate cadmium in its leaves was also noteworthy, with levels exceeding those generally considered harmful for plants. This suggests potential use for teak in the phytoremediation of cadmium-contaminated soils, although further studies are required to validate these findings.

An individual of the genus *Aegiphila* was also found in the area, though species-level identification was not possible due to the absence of reproductive organs. *Aegiphila* species occur throughout the Neotropics and have been recorded in natural regeneration areas of iron mining sites (GUEVARA, 2005). In this study, the individual showed signs of stress, such as poor growth and disease symptoms, yet it displayed promise in phytoextracting nickel, copper, cadmium, and lead.

Further studies are needed to assess the phytoaccumulation potential of *Aegiphila* species, particularly in Acre, as there is limited literature on their metal absorption capabilities. However, *Aegiphila* species have demonstrated good development in contaminated substrates, such as sewage sludge (SANTOS, 2013; CALDEIRA et al., 2018), although metal absorption was not detailed.

An individual *Ceiba pentandra* was also identified. Native to the Amazon and widely cultivated in Brazil, *C. pentandra* is known for adsorbing heavy metals through its fibers and residues (CHUNG et al., 2008; HIDAYAT et al., 2021), though its potential for phytoremediation is still underexplored. The individual exhibited necrotic spots, indicating poor health. Despite this, the tree phytoextracted three of the five tested metals: copper, cadmium, and chromium. Therefore, *C. pentandra* and *Aegiphila*, both native species, show promise for phytoremediation in southeastern Amazonia and warrant further investigation.

CONCLUSION

All the species studied absorbed large quantities of metals through their roots, exceeding the levels found in the soil surrounding the adult trees at the deactivated dump, indicating metal bioaccumulation. All the species demonstrated tolerance to chromium, with concentrations in leaves and roots higher than those tolerated by sensitive plants, proving effective for soil decontamination of this metal.

R. communis exhibited tolerance and phytoextraction capabilities for lead. It also accumulated high levels of chromium, nickel, and copper in its roots, demonstrating tolerance to these metals. *L. leucocephala* accumulated lead concentrations considered toxic for plants in its roots without showing signs of toxicity, indicating its tolerance and potential for lead phytostabilization.

The species from the genus *Aegiphila* phytoextracted toxic levels of chromium, nickel, and copper in its leaves and showed a high lead translocation capacity. However, it displayed several signs of stress in the field. *C. pentandra* and *T. grandis* showed cadmium concentrations above the levels considered normal for plants. Despite this, only teak (*T. grandis*) maintained good field conditions with healthy leaves and fruits. *T. grandis* also accumulated high concentrations of copper in its leaves, indicating potential for use in phytoremediation.

Further investigation is needed to evaluate the phytoextraction capacity and metal tolerance of *Aegiphila sp.* and *C. pentandra* in controlled greenhouse conditions. Although both showed signs of phytotoxicity, they exhibited good metal translocation indices and are native to the Amazon.

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