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Evaluation of Phytoremediation Potentials of Some Plants Species of Serra da Tiririca, Rio de Janeiro, Brazil

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Authors' contributions

This work was carried out in collaboration between all authors. Author APB designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors VJV and ACPSA managed the analyses of the study. Author DAL managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The aim of this study was to present new information on the main plant species occurring in the Serra da Tiririca State Park capable of potentially acting as phytormediators. This was based on a floristic inventory as well as field research. The floristic inventory resulted in the recording of 69 endemic plant species in the State Park of Serra da Tiririca. Among these the following known hyperacummulator families occurred: Brassicaceae, Euphorbiaceae, Fabaceae (Leguminosae), Asteraceae and Lamiaceae. The main phytoremediator species identified and the mechanism by

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which they perform the remediation process, respectively, were: *Thlaspi caerulescens* J. and C. Presl, *Pteris sp*., *Berkheya coddii* Ans, Phytoextraction; *Brassica juncea* L., *Salicornia bigelovvi* Torr, Phytovolatilization; *Zea mays* L., *Eucaliptus spp*., *Agrostis cappilares* L., *Festuca rubra* L., Phytostabilization; *Eichhornia crassipes*, Phytodetoxification; *Helianthus sp*., *Eichhornia crassipes* Mart., *Pteris sp*., Rhizofiltration and *Brassica juncea* L., Rhizovilatilization. For the mediation of contaminated soils, these species identified in this study present a potential ability to perform phytoremediation process.

Keywords: Phytoremediation; Serra da Tiririca; soil contamination.

1. INTRODUCTION

The term phytoremediation encompasses all processes involved in the remediation of soils, sediments and aquifer systems contaminated by the selection and use of plant species to reduce the concentrations or toxic effects of contaminants in the environments [1-3]. This process can be applied to "hijack" the contaminants from soil and water, and these organic (petroleum hydrocarbons and pesticides) or inorganic (chemical toxic and radioactive metals).

In general, the contaminants removal from the soil/ water by plants can focus in the aerial part of the same, as well as the root. This is due mainly by physiological and biochemical capacity that the plants should adapt to different environmental conditions [4]. Contaminants that remain on the ground can be converted metabolically by the action of enzymes or microorganisms (bacterial colonies or mycorrhizal fungi) associated symbiotically with the roots, being the rhizodegradation coupled with phytoacumulation of metals as the main types of phytoremediation [5].

Phytoremediation can be applied with different processes depending on the applicability and type of contaminant. Examples of these processes are [5,6]:

- Rhizodegradation: Consisting of degradation of the pollutant by the association of microorganisms with the roots and then phytoextraction;
- Phytoaccumulation: Which is the accumulation of metals that showed no change in roots or tissues of aerial part of the plant, once absorbed by the root contaminants may suffer;
- Phytodegradation: Consisting degradation the detoxification in aerial plant tissues, or;
- Phytovolatilisation: When the compounds are volatilized from the leaves to the atmosphere.

Thus, phytoremediation becomes a cost-effective method technology compared with other clean-up methods or decontamination of soil/ water. This technology can be up to ten times more economically viable, it increasingly it is seen with good eyes, as well as being an easy application and control technology. Therefore, the phytoremediation becomes a growing practice on the world stage, especially in the USA, Europe and own text, though still few studies in Brazil [7].

However, phytoremediation technology involves the use of living organisms whose survival and development are dependent on the environmental characteristics that vary with the different application sites, which implies a greater number of variables to be considered, as compared to the conventional physical-chemical treatments. A technology that can be used, with appropriate restrictions in cases of contamination by metals, pesticides, solvents, explosives, oil and slurry, and therefore applies to a large variety of pollutants, including some known to be recalcitrant. Phytoremediation has favorable aesthetics, because the print site remediation aspect of an area of agricultural crops or landscaping and other associated advantages such as low cost of deployment and maintenance and the possibility of re-use of soil. The produced plant material can be used for activities such as making furniture, power generation, fiber production and others [8].

The economic and technological feasibility of application of this process are related to the time to get results that are dependent on the plant cycle, the concentration of the pollutant in the soil and the presence of other toxins that must be within the limits tolerated by the plant. Another factor that should be considered is the risk of mobilizing plants or the possibility of the contaminant leaking into to the environment by volatilization or the food chain [9].

The recovery of contaminated areas can be accomplished in two different ways or techniques, *ex situ* or *in situ*. The *ex situ* techniques, such as excavating, incineration, transportation, among other things, bring with it environmental risks and so arises the possibility of using a technique *in situ*. Therefore, the phytoremediation becomes fully applicable.

For the remediation of soils contaminated by heavy metals, various techniques have been proposed. These technologies are very variable, depending on the contaminated matrix, the nature of the pollutant, level of contamination and the availability of resources. Phytoremediation uses plants and their associated microorganisms, targeting the *in situ* treatment of contaminated soils. This technology presents as main advantages the low cost and the possibility of application in large areas, besides being an *in situ* remediation technique, not causing secondary contamination. This technique also promotes revegetation of contaminated areas, which helps protect the soil against wind and water erosion, while aesthetically improve the degraded area [10].

It is desirable that the phytoremediation process plant species exhibit rapid growth, high biomass production, competitiveness, vigor and tolerance to pollution. Thus, it is increasingly seen with good to develop studies, in order to select a large number of plant species (herbaceous, tree and shrub) with the potential to act as phytoremediator in areas contaminated by heavy metals.

This study aimed to identify the main phytoremediator species present in the Serra da Tiririca State Park and analyze the mechanisms by which these plants perform the recovery of contaminated areas resulting from human activities throughout its length.

2. MATERIALS AND METHODS

The Serra da Tiririca (Fig. 1) is a portion of the Atlantic Forest inserted in the coastal range of the Serra do Mar, between the cities of Niterói and Maricá in the State of Rio de Janeiro. The vegetation presents a scleromorphic general appearance, with intense falling leaves in the drier months. However, it is characterized by dense forest and rocky outcrops, and its scleromorphic aspect associated with regional climate, proximity to the sea and the presence of shallow soils. The floristic survey carried out by Barros [11] recorded 907 species of Magnoliophyta belonging to 434 genera and 97 families, and 122 species considered ruderal. This study concentrated on the following families as those with the highest: Leguminosae (85 spp.), Rubiaceae (54 spp.), Myrtaceae (55 spp.), Euphorbiaceae (42 spp.), Bromeliaceae (41 spp.), Sapindaceae (33 spp.), Bignoniaceae (29 spp.), Orchidaceae (28 spp.), Araceae (25 spp.) and Asteraceae (25 spp.). The woody plants represent 35.8% of the flora, followed by creepers (21.9%), herbs (18.4%), shrubs (16.9%), epiphytes (4.9%), hemiepiphytes (1.8 %) and parasites (0.3%).

The floristic inventory of the BARROS [11] and the management plan of State Serra da Tiririca Park [12] were considered for the survey of endemic plant species of this park. A field survey was conducted considering the collection and identification of plant specimens and subsequent comparison with vouchers deposited in the Jardim Botânico da cidade do Rio de Janeiro (Botanical Garden of City of Rio de Janeiro).

Of the endemic species found in the park, those that had potential ability to perform phytoremediation processes. Only those species whose phytoremediation was proven in literature were considered [13-17].

Some species have been identified as hyperaccumulators of heavy metals (Zn, Ni, Mn, Cu, Co and Cd), metalloids (As) and non-metals (If) and a greater number of Ni hyperaccumulator. Considered hyperaccumulators are those plants able to accumulate more than 100 mg kg^{-1} of Cd, 1000 mg $kg^{-}1$ Ni, Pb and Cu, or 10,000 mg kg^{-1} of Zn and Mn for dry matter [18].

3. RESULTS AND DISCUSSION

Phytoremediation uses plants and microbiota to "hijack" the contaminants from soil and water, and these organic (petroleum hydrocarbons and pesticides) or inorganic (chemical toxic and radioactive metals). Phytoremediation encompasses various types of processes, namely: Phytoextraction, phytostabilization, phytostimulation, phytovolatilization, phytodegradation and rhizofiltration [6]. In general, the contaminants are removed from soil/ water by plants can focus in the aerial part of the same, as well as the root. This is due mainly by physiological and biochemical capacity that the plants should adapt to different environmental conditions [4].

Thus, phytoremediation becomes a cost-effective method technology compared with other clean-up methods or decontamination of soil/ water. This technology can be up to ten times more economically viable as well as being an easy application and control technology. Therefore, the phytoremediation becomes a growing practice on the world stage, especially in the USA, Europe and, though still few studies, also in Brazil [7].

It is desirable that the phytoremediation process involves plant species that exhibit rapid growth, high biomass production, competitiveness, vigor and tolerance to pollution. Thus, it is necessary to develop studies, in order to select a large number of plant species (herbaceous, tree and shrub) with the potential to act as phytoremediator in areas contaminated by heavy metals.

Sixty-nine endemic species of the State of Rio de Janeiro were recorded in the State Park of Serra da Tiririca (PESET). Among these species there are families of hyperaccumulator plants: Brassicaceae, Euphorbiaceae, Fabaceae (Leguminosae), Asteraceae and Lamiaceae (Table 1). The first characterized hyperaccumulator plants were family members of Brassicaceae and Fabaceae in temperate, being represented by the family of Euphorbiaceae in the tropics [19]. Hyperaccumulator plants are also found in Asteraceae, Lamiaceae and Scrophulariaceae. For example: *Indian mustard*, *Brassica juncea* for lead (Pb), chromium (Cr), cadmium (Cd), copper (Cu), nickel (Ni), zinc (Zn), strontium (Sr), boron (B) and selenium (Se), *Thlaspi caerulescens* for nickel and zinc (Ni and Zn), sunflower (*Helianthus annuus*), tobacco (*Nicotiniana tabacum*) and *Alyssum wufenianum* for Ni [20].

A hyperaccumulator plant must have the following characteristics: a) high rate of contaminant buildup even at low concentrations; b) accumulate many contaminants concurrently; c) high growth rate and biomass production, d) resistance to pests and diseases and e) tolerance to contaminants [17].

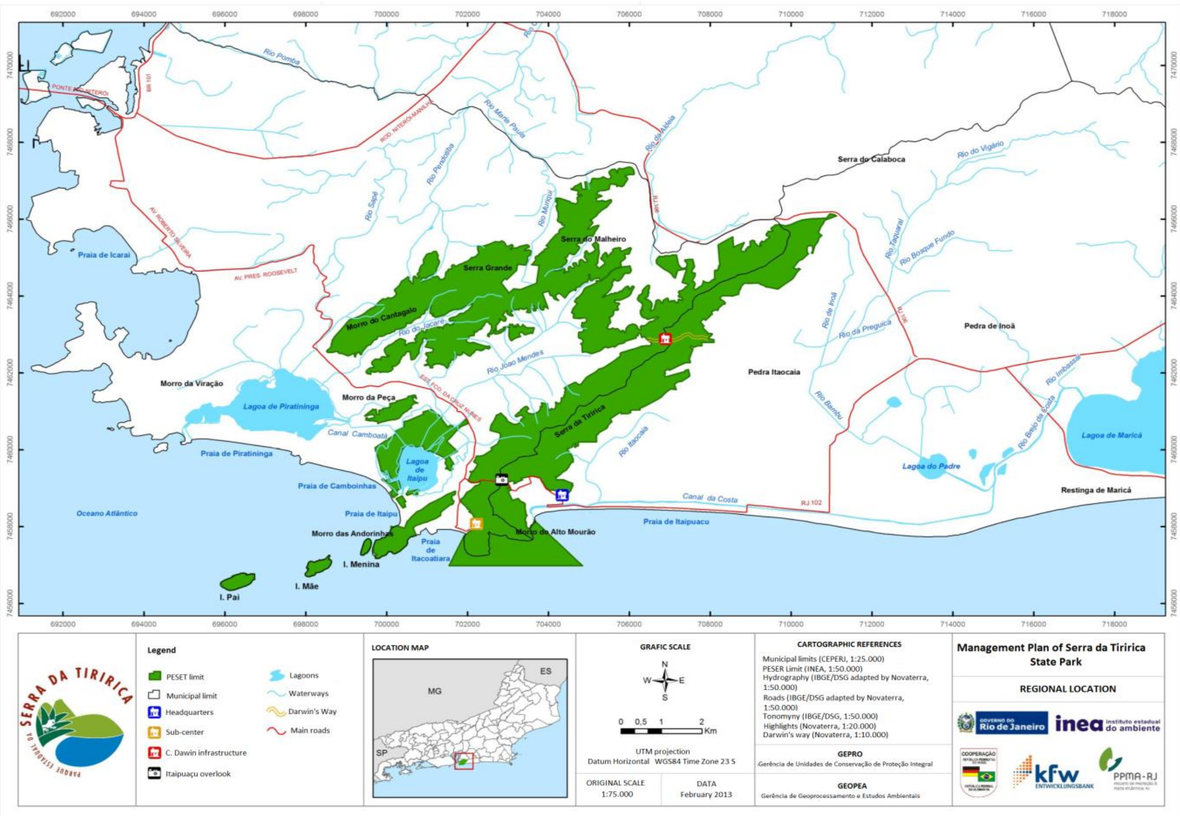

Fig. 1. Map of the Serra da Tiririca State Park, Rio de Janeiro, Brazil
Source: Management Plan of Serra da Tiririca State Park [12]

Table 1. Endemic plants of the state of Rio de Janeiro occurring in the Serra da Tiririca, Niterói and Maricá, RJ [11]

Families	***Species***
Acanthaceae	*Justicia beyrichii* (Nees) Lindau
	Schaueria calycotricha (Link & Otto) Nees
Annonaceae	*Duguetia sessilis* (Vell.) Maas
	Guatteria reflexa R.E.Fr.
Araceae	*Anthurium harrisii* (Grah.) Enoll.
	Anthurium luschnathianum Kunth
	Anthurium maximiliani Schott
	Anthurium sucrei G.M. Barroso
	Anthurium validinervium Engl
	Philodendron speciosum Schott ex Engl.
Bromeliaceae	*Aechmea fasciata* (Lindl.)Baker *var. fasciata*
	Alcantarea glaziouana (Lemaire) Leme
	Cryptanthus acaulis (Lindl.) Beer
	Neoregelia cruenta (R. Graham) L.B. Smith
	Neoregelia sapiatibensis E. Pereira & L.A. Pereira
	Tillandsia araujei Mez
	Vriesea costae E. Leme & B. Rezende
	Vriesea eltoniana Pereira & Ivo
Cactaceae	*Rhipsalis cereoides (*Backeb & Voll.) Backeb.
	Rhipsalis mesembryanthemoides Haworth
Clusiaceae	*Kielmeyera rizziniana* Saddi
Connaraceae	*Connarus nodosus* Baker
Cucurbitaceae	*Wilbrandia glaziovi* Cogn.
Erythroxylaceae	*Erythroxylum gaudichaudii* Peyr.
	Erythroxylum magnoliifolium A. St. Hil.
Euphorbiaceae	*Algernonia brasiliensis* Baill.
Lauraceae	*Ocotea microbotrys (*Meisn.) Mez
	Ocotea schotii (Miesn.) Mez
Lecythidaceae	*Couratari pyramidata* (Vell.) Knuth
	Eschweilera compressa (Vell.) Miers
Leguminosae	*Inga lanceifolia* Benth.
	Inga lenticellata Benth.
	Machaerium firmum Benth.
	Pseudopiptadenia schumanniana (Taub.) Lewis & M. Lima
	Senegalia mikanii (Benth.) Seigler & Ebinger
	Senegalia pteridifolia (Benth.) Seigler & Ebinger
Loranthaceae	*Struthanthus maricensis* Rizz.
Malpighiaceae	*Banisteriopsis sellowiana* (A. Juss.) B. Gates
	Stigmaphyllon gayanum A. Juss.
	Stigmaphyllon vitifolium A. Juss.
Malvaceae	*Abutilon anodoides* A. St. Hil. et Naud.
Marantaceae	*Calathea sphaerocephala* K. Schum.
Monimiaceae	*Mollinedia glabra* (Spreng.) Perkins
	Mollinedia lamprophylla Perkins
	Mollinedia longifolia Tulasne
Myrtaceae	*Campomanesia laurifolia* Gardn.
	Eugenia excelsa O. Berg
	Eugenia marambaiensis M.C. Souza et M.P. Morim
	Marlierea choriophylla Kiaersk.
	Marlierea racemosa (Vell.) Kiaersk.
Passifloraceae	*Passiflora farneyi* Pessoa & Cervi
Piperaceae	*Peperomia incana* (Haw.) Hook.
Rubiaceae	*Coussarea capitata* (Benth.) Benth. et Hook. f.

Families	***Species***
	Faramea calyciflora A. Rich. ex DC.
	Faramea macrocalyx Müll. Arg.
	Mitracarpus lhotzkyanus Cham.
	Posoqueria acutifolia Mart.
	Psychotria rauwolfioides Standl.
	Psycotria stenocalyx Müll. Arg.
	Psychotria subspathacea Müll. Arg.
	Psychotria tenuinervis Müll. Arg.
	Psychotria umbellurigera (Müll. Arg.) Standl.
	Rudgea discolor Benth.
	Rudgea eugenioides Standl.
	Rudgea eugenioides Standl.
	Rudgea interrupta Benth.
	Rudgea umbrosa Müll.Arg.
Simaroubaceae	*Picrammia grandifolia* Engler
Solanaceae	*Metternichia princeps* Mikan *var. princeps*

Accordingly, literature has already registered about 450 hyperaccumulator plants; most are found in contaminated areas in Europe, United States, New Zealand and Australia [21]. Table 2 shows some examples of plants used in phytoremediation. Classically, the species *Brassica juncea*, *Aeolanthus biformifolius*, *Thlaspi caerulescens* and *Alyssum bertolonii* are examples of accumulating plants for Pb, Cu, Co, Ni and Zn, respectively. In addition to these species, other species have been identified in the plant as hyperaccumulators of heavy metals: *Cedrela odorata* L., *Baccharis serrulata* (Lam.) Pres, *Baccharis dracunculifolia* DC, *Baccharis trinervis* Pers, *Carnavália sp*. and *Jatropha sp*. The hyperaccumulation of heavy metals depends on the plant species, soil conditions pH, organic matter content and cation exchange capacity [22].

Some species of plants native to the Atlantic Forest have been identified in the area and have potential for phytoremediation of contaminated soils. The ipe-purple (*Tabebuia impetiginosa*) [16], pink cedar (*Cedrela fissilis*) [16], canafístula (*Peltophorum dubium*) [13], the embaúba (*Cecropia pachystachya*) [14], mimosa (*P. rigida*) [13] and timbaúva (*Enterolobium contortisiliquum*) [13] are some examples.

The *Tibouchina granulosa* (Desc.) Cogn. (Melastomataceae), known by the popular name of "Quaresmeira" presenting flowers with shades ranging from pink to purple and therefore has the potential to be used as an ornamental plant. This species had been reported as a suitable plant for the phytorremediation of soil contaminated with up to 6% oil [15]. This shrubby species is observed on the edges of outcrops in contact with the adjacent forest, Costão Itacoatiara, Morro das Andorinhas and Alto Mourão.

Some plants have potential for extracting various metals from the soil, others are more specific. *Brassica juncea* L. has the potential to remediate soils with high levels of Pb, Cr, Cd, Cu, Ni, Zn, Sr, B and Se; *Thlaspi caerulescens* J. and C. Presl to phytoremediate Cd, Ni and Zn; *Helianthus annuus* L. and *Alyssum caufenianum* to extract Ni. Table 3 show some phytoremediators plant species found in the Serra da Tiririca, their uses and specific remediation mechanisms [13-15,17,20].

The mechanisms involved in the tolerance of plants to high concentrations of metals in the soil are varied and poorly defined. These are related to differences in the structure and function of cell membranes, the removal of storage and metabolism ions in fixed and/ or insoluble forms in various organs and organelles, changes in metabolic patterns, among others [23]. According to these authors, phytochelatin training was the main reason for the tolerance of some species to the high Zn and Cd content in the soil. Increasing the concentration of heavy metals in the cytoplasm of plants leads to activation of phytochelatin synthesis, which sequesters metal ions, avoiding critical concentrations of these cells.

The manure, landfills of waste, can be treated by phytoremediation process. To grow, plants require sixteen chemical elements considered essential, has positive effects on the development of plants. These macronutrients (N, P, K, Ca, Mg and S) and micronutrients (Cu, Fe, Mn, Zn, Mo, B, Al and Cl) are removed from the

Table 2. Plants employed in the phytoremediation of contaminated soils by heavy metals [17]

Plant	Contaminant / Heavy metals / Metals
Agrostis capillaris	Zn
Agrotis stolonifera	Cu
Ambrósia artemisiifilia	Pb
Azolla pinnata	Pb, Cu, Cd, Fe, Hg
Bacopa monnieri	Cu, Cr, Fe, Mn, Cd, Pb
Brassica juncea	U, Zn, Cd
Brassica napus	Zn, Cd
Brassica rapa	Zn, Cd
Ceratophyllum demersum	Cu, Cr, Fe, Mn, Cd, Pb
Eichhornia crassipes	Pb, Cu, Cd, Fe, Hg
Festuca rubra	Zn
Helianthus annuus	Heavy metals, U
Hydrocotyle umbellata	Pb, Cu, Cd, Fe, Hg
Hygrorrhiza aristata	Cu, Cr, Fe, Mn, Cd, Pb
Lemna minor	Pb, Cu, Cd, Fe, Hg
Lemna polyrrhiza	Zn
Silene cucubalus	Zn
Silene itálica pers.	Ni, Cd
Spirodela polyrrhiza	Cu, Cr, Fe, Mn, Cd, Pb

Table 3. Some phytoremediator species and their uses [13-15,17,20]

Contaminants	Species	Mechanisms
Zn and Cd.	*T. caerulenscens*	Phytoextraction
As and Ni.	*Pteris sp.* *B. coddii.*	Phytoextraction
Organic and Inorganic HG.	*B. juncea*	Phytovolatilization
Zn, Cd, Cu, Pb, Mn and As.	*Z. mays* *Eucaliptus spp.* *A. cappilaris* *F. rubra*	Phytostabilization
Inorganic SE.	*Salicornia bigelovvi*	Phytovolatilization
U, As E Hg.	*Helianthus sp.* *E. crassipes,* *Pteris sp.*	Rhizofiltration
Cr.	*E. crassipes.*	Phytodetoxification
Inorganic HG.	*B. juncea*	Rhizovolatilization

soil; C, H and O are removed from the air as carbon dioxide and water. These nutrients can be found in large concentrations in the slurry. Co, Ni, Si, V and Cd are considered beneficial to plant growth and can also be found in the slurry. The removal of toxic metals can be efficiently performed by phytoremediation, since the slurry can be used as a fertilizer for Eucalyptus plant with efficiency phytoextraction of metals. After saturation, the metals can be recovered in the regenerated biomass [24].

4. CONCLUSION

Among the 69 endemic plant species of the State of Rio de Janeiro identified at Park Serra da Tiririca, some plant species were chosen with potential application in phytoremediation. Some phytoremediator plant species found in the park and the mechanism by which perform they the remediation process are:

- Phytoextraction: *T. caerulescens* J. and C. Presl. (Zn and Cd.), *Pteris* sp., and *B. coddii* Ans. (As and Ni);
- Phytovolatilization: *B. juncea* L. (Organic and inorganic Hg), *S. bigelovvi* Torr. (Inorganic Se.);
- Phytostabilization: *Z. mays* L., *Eucaliptus* spp., *A. cappilaris* L., *F. rubra* L. (Zn, Cd, Cu, Pb, Mn and As);

- Phytodetoxification: *E. crassipes* Mart. (CR inorganic Hg);
- Rhizofiltration: Helianthus sp., *E. crassipes* Mart., *Pteris* sp. (U, As e Hg);
- Rhizovolatilization: *B. juncea* L. (CR inorganic Hg).

The application of an *in situ* treatment with the use of plants enable a remediation process with less environmental impact together with the recovery of degraded areas. This strategy can be adopted with a low initial cost, as it enables the use of natural resources already present in the locality, and can be conducted in partnership with research institutes, universities and volunteers.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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