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Expanding the occurrence of *Parmotrema enteroxanthum* (*Parmeliaceae*, lichenized *Ascomycota*) in South America: first record from Brazil, and notes on distribution and conservation assessment

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Abstract. *Parmotrema enteroxanthum* is a restricted distribution foliose lichen, easily recognized by its yellow medulla and salazinic acid content. Previously known only from Venezuela, Colombia, and Bolivia, its distribution in South America remains poorly understood. This study documents the first record of the species in Brazil, with notes on ecology and conservation. Field collections were conducted from Cerrado areas in the state of Maranhão, northeastern Brazil. Morphological and chemical analyses were performed using microscopy, spot tests, and thin-layer chromatography. Distribution data were compiled from GBIF, and conservation status was preliminarily assessed using GeoCat, based on IUCN criteria. *Parmotrema enteroxanthum* was recorded in *cerradão* vegetation, extending its range into Brazil and the Cerrado domain (Brazilian Savanna). The species occurs in seasonally dry and rainforest habitats (open/ exposed microhabitats) in South America. Geospatial analysis indicated a wide Extent of Occurrence (~3.6 million km^2), but a very restricted Area of Occupancy (16 km^2), suggesting a fragmented distribution. According to IUCN criteria, the species may be considered potentially Endangered (EN) due to its low number of localities and ongoing habitat loss. This finding underscores the Cerrado as both a center of lichen diversity and a highly threatened biome.

Key words: Cerrado, conservation, lichens, Maranhão state, Northeast region, salazinic acid

Introduction

The ongoing loss and fragmentation of natural habitats, driven primarily by land-use change, agriculture, and urban expansion, represent critical threats to global biodiversity (Haddad et al. 2015). While these impacts are widely recognized for vascular plants and animals, lichenized fungi, organisms resulting from a symbiotic relationship between a mycobiont and a photobiont, remain largely overlooked in conservation agendas. Due to their sensitivity to environmental changes and dependence on stable microhabitats, lichens are particularly vulnerable to habitat degradation (Scheidegger & Werth 2009). In this context, documenting the occurrence and distribution of lichen species is essential, not only for understanding their ecological roles, but also for establishing effective conservation strategies (Allen & Lendemer 2016).

Parmotrema A. Massal. is among the most species-rich genera of foliose lichens in the family *Parmeliaceae*, comprising approximately 300 taxa worldwide (Lücking et al. 2017). Its diversity is especially pronounced in tropical and subtropical regions, with South America standing out as a major center of richness (Blanco et al. 2006; Crespo et al. 2010), covering approximately 220 known species in tropical regions, with around 200 spp. reported in Brazil (Ciecoski et al. 2024; Aptroot et al. 2025). Many lichens species, including the genus *Parmotrema*, exhibit ecological plasticity, but others are more habitat-restricted and thus more susceptible to environmental pressures (Vitorino et al. 2025). Despite its high diversity, the genus remains poorly documented in several regions of Brazil, particularly in northeast region, where the scarcity of studies and the limited number of active lichenologists have hindered a proper assessment of its diversity.

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The Cerrado domains, which covers nearly 2 million km^2 across central Brazil, is recognized for its ecological heterogeneity and high levels of plant and fungal endemism (Alencar et al. 2020). In the state of Maranhão, this biome accounts for approximately 60% of the territory (Spinelli-Araujo et al. 2016). However, the Cerrado is also one of the most threatened ecosystems in the world, with more than half of its original vegetation already lost to agricultural expansion and less than 2.5% of its area under legal protection (Myers et al. 2000; Klink & Machado 2005). Lichenological research in this region remains scarce, and only eight *Parmotrema* species have been reported so far from Cerrado areas in Maranhão (Aptroot et al. 2017; Santos et al. 2021; Cunha-Dias et al. 2025; Nascimento et al. 2025), suggesting a significant knowledge gap.

Parmotrema enteroxanthum Hale is a species belonging to the salazinic acid chemical group (Spielmann & Marcelli 2020), and it is unique within the genus for exhibiting a distinctive yellow medulla visible on the lower surface of the thallus. The species was originally described from Venezuela (Hale 1977) and has since been reported from a few additional localities in central to northern South America, including Colombia and Bolivia (Aguirre-C. & Rangel-Ch. 2007; Flakus et al. 2016, respectively). However, these occurrences are geographically isolated, and its distribution remains poorly known, likely due to limited sampling across suitable habitats.

We report the first record of *P. enteroxanthum* in Brazil, based on material collected in the Cerrado area of Maranhão. Our findings expand its known range and underscore the importance of continued surveys in underexplored biomes for the conservation of lichen diversity.

Materials and methods

The municipality of São João do Paraíso (06°27′34″S; 47°03′24″W), south mesoregion of the Maranhão State, covers territorial areas of 2,053.8 km^2. The regional climate is characterized by an average annual temperature of 26°C and means annual precipitation of approximately 1,400 mm (Correia-Filho 2011).

Field expeditions were conducted using a random sampling approach, involving active searches for lichens on tree and shrub branches and trunks, as well as on rock surfaces, in natural vegetation areas (Cáceres et al. 2008). Specimen collection and substrate removal followed the procedures outlined by Hale (1979) and Benatti & Marcelli (2007). Specimens were identified using a Zeiss Stemi 305 stereomicroscope and a Zeiss Primo Star – 3 optical microscope, based on morphological, anatomical, and chemical characterization of lichen thallus.

Morphological characterization followed the protocol developed by the Grupo de Estudos Liquenológicos (GEL) of the Instituto de Botânica de São Paulo, as described in Canêz & Marcelli (2006). The main characters analyzed included: thallus color, shape, size, and adherence; lobe characteristics (apex shape, margins, ramification); vegetative propagules – pustules and soredia (type, distribution on thallus, shape); medulla (color); lower surface features (color, brightness, margins); rhizine morphology (color, branching, and number); and, when present, apothecia (shape, type, position), pycnidia (color and distribution), and conidia (type and size).

Chemical analyses spot tests were conducted on the thallus and medulla of the lichen using the following reagents: potassium hydroxide 10% (K), sodium hypochlorite 40% (C), and both reagents combined (KC). Additionally, ultraviolet (UV) light exposure, and thin-layer chromatography (TLC): solvent systems A (toluene, dioxane, and acetic acid in a ratio of 180:45:5) and C (toluene and acetic acid in a ratio of 170:30) following the methodologies of Huneck & Yoshimura (1996), Bungartz (2002), Orange et al. (2010), and Elix (2014).

We used an occurrence dataset with records from GBIF (https://doi.org/10.15468/dl.s263hz). An occurrence map was constructed using software QGIS Development Team (https://qgis.org/; QGIS 2023). For the preliminarily assessment of conservation status for *P. enteroxanthum*, we followed the IUCN criteria for extent of occurrence – Criteria B (IUCN 2024) and used the extension of occurrence (EOO) and the area of occupation (AOO). The EOO and AOO were calculated with the Geospatial Conservation Assessment Tool – GeoCAT (https://geocat.iucnredlist.org/; Bachman et al. 2011) with a cell width of 2 × 2 km.

Results and discussion

The first record of *Parmotrema enteroxanthum* from Brazil, based on specimens collected in a *cerradão* area in São João do Paraíso (Maranhão), suggests ecological affinities broadly consistent with those inferred from previous records in other South American regions (Fig. 1). Based on available locality data, the species has been recorded in relatively open or well-lit microhabitats, including canopy gaps, exposed bark, and occasionally sun-exposed rock surfaces, across contrasting environmental settings. Although these records span both seasonally dry ecosystems – such as the Cerrado and the Bolivian Chaco – and humid tropical environments, notably the montane forests of the Magdalena Valley in Colombia, they share structural features such as heterogeneous canopy cover and the availability of illuminated substrates. These conditions may favor the establishment of corticolous lichens, although broader sampling is needed to better characterize the ecological preferences of the species.

The disjunct distribution of *P. enteroxanthum*, spanning the Andes of Venezuela and Colombia, the Dry Chaco of Bolivia, and now the Brazilian Cerrado, likely reflects uneven sampling effort rather than true ecological discontinuity (Fig. 1). Notably, many previous records stem from better-explored or protected areas, whereas extensive regions of central and northern South America (including inland savannas, transitional dry forests, and rainforest) remain largely underexplored for lichen diversity. This new Brazilian record underscores the ecological breadth of *P. enteroxanthum* and

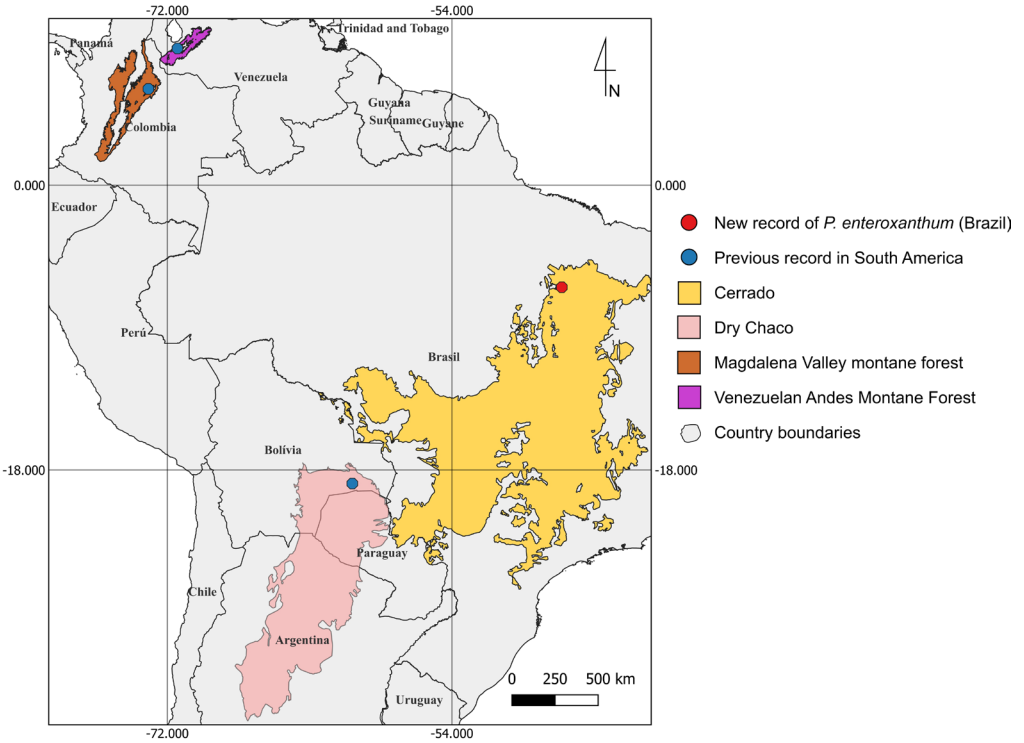

Figure 1. Geographic distribution with an emphasis on a new record of *Parmotrema enteroxanthum* in Brazil, expanding its known distribution beyond previously documented localities in South America. The species is now confirmed within the Cerrado domain (Maranhão State), as mapped. Occurrence data were obtained from GBIF, and ecoregions follow the WWF (https://www.worldwildlife.org/) classification.

highlights the importance of surveys in the Cerrado and similar environments, where additional undocumented populations may still occur.

Until recently, *P. enteroxanthum* was considered the only South American species of the genus characterized by the presence of salazinic acid combined with a yellow medulla, which made its recognition straightforward (Spielmann & Marcelli 2020). This scenario changed with the description of a new taxon (*P. hypoflavum* Marcelli & Ciecoski) by Ciecoski et al. (2024), also presenting this chemical profile, but differing by the presence of marginal cilia and conspicuous maculae, both consistently absent in *P. enteroxanthum*. These diagnostic traits allow a reliable separation between the two species (Table 1).

Taxonomy

Parmotrema entroxanthum Hale, Mycotaxon 5(2): 434. 1977. (Fig. 2)

Type: Venezuela, Merida: La Carbonera, sector El Pedregal, on rocks in open pasture, 2,100 m alt., 19-III-1975, M.E. Hale & M. Lopez Figueiras 44177 (holotype – US, not seen; isotypes – MERF, UPS, image!)

Description. Thallus corticolous; greenish-gray, 8–20 cm long, lobed, loosely adnate, subcoriaceous. Lobes 4–12 mm wide, with irregular branching, from laterally overlapping to clustered, rounded apex, flat; margin flat to ascending or involute, crenate to undulate; upper surface smooth to cracked-reticulate, glossy, sometimes rough on older parts. Lobules ~1–1.8 mm long

Table 1. Comparative characteristics between the two species of *Parmotrema* with salazinic acid medullary and yellow medulla.

Characteristics / Species	*Parmotrema enteroxanthum* (based on our specimens; and Spielmann & Marcelli 2020)	*Parmotrema hypoflavum* (based on Ciecoski et al. 2024)
Lacinulae / Lobules	Adventitious, 1–1.8 mm long × 1.5–3.5 mm wide, flats, rounded	Marginal, 1.5–2.0 mm long × 0.5–1.0 mm wide; anisotomous to irregularly ramified
Cilia	Absent	Present; black, 0.4–1.5 mm
Maculae	Absent	Rare; reticular
Medulla	Yellow (predominantly in lower surface)	White in some points, and yellowish (major parts)
Vegetative propagule	Pustules; laminal, coarse, coralloid aspect, corticated appearance	Soralia subapical on the lacinules, rare marginal to submarginal; orbicular; soredia common the farinose and abundant the granular, ecorticated
Ascospore	Ellipsoid; 27–32 × 11–16.5 µm	Absent
Pycnidia / conidia	Pycnidia frequent; conidia sublageniform, ~7.5 µm long	Absents
Chemistry	Atranorin and chloroatranorin (cortical); salazinic and consalazinic acids (medullary)	Atranorin (cortical); salazinic and secalonic acids (medullary)

Figure 2. *Parmotrema enteroxanthum* (J.S. Santos 27). Scale = 1 cm.

× 1.5–3.5 mm wide, adventitious, flats, rounded. Maculae, cilia, and isidia true absent. Pustules laminal, coarse, with a coralloid aspect and a corticated appearance. Medulla yellow predominantly on the lower surface. Lower surface black, glossy, smooth to rough, usually with scars; margin dark brown, 1–4 mm wide, bare, glossy, smooth to rough, sometimes papillate; rhizines black, usually simple, sometimes forked, 0.30–5.50 × 0.02–0.20 mm, frequent and abundant, distributed in groups. Apothecia cupuliform 1.5–2.0 mm in diameter, stipitate, laminate, margin smooth to crenulate, amphitecium smooth, disc brown, imperforate; ascospores ellipsoid, 27–32 × 11–16.5 µm. Pycnidia submarginal to laminal, frequent, black ostiole; conidia sublageniform, ~7.5 µm long.

Chemistry. (spot tests and TLC): Cortex – K+ yellow, UV–; medulla – K+ yellow → red, C+ yellow, KC+ yellow → red, UV+ light green. Atranorin and chloroatranorin (cortical); salazinic and consalazinic acids (medullary).

Distribution. First record for Brazil (Maranhão). Previously known only from Venezuela (Hale 1977; Spielmann & Marcelli 2020), Colombia (Aguirre-C. & Rangel-Ch. 2007), and Bolivia (Flakus et al. 2016).

Ecology and habitat. *Parmotrema enteroxanthum* occurs predominantly in seasonally dry and rainforest environments, including *cerradão* vegetation in the Brazilian Cerrado, rainforest montane in the Venezuelan Andes, the Magdalena montane forests in Colombia, and Chaco woodlands in Bolivia (Fig. 1). These habitats are characterized by open to semi-open canopies, and a pronounced alternation between dry and humid periods. The species is saxicolous [type specimens (Hale 1977; Spielmann & Marcelli 2020)] or corticolous (our specimens), developing mainly on exposed bark of trees and shrubs, or rocks.

The thallus of *P. enteroxanthum* observed of native woody vegetation in *cerradão* areas, frequently in open sites with lighting. No saxicolous specimens were found in the Brazilian material, although the type collection was originally described from rocks in Venezuela. The occurrence on corticolous substrates in Maranhão, together with similar observations from other South American records, indicates that the species can colonize a variety of substrates, but prefers open microhabitats, whether forest or non-forest environments.

Preliminary IUCN conservation assessment. The conservation assessment of *P. enteroxanthum* indicates that, despite the wide geographic separation among known localities, the species exhibits a large Extent of Occurrence (EOO) of approximately 3.6 million km^2, contrasted by a highly restricted Area of Occupancy (AOO) of only 16 km^2, distributed across four isolated sites. These sites occur in environmentally vulnerable and heavily anthropogenically impacted regions, including the Venezuelan Andes, the Magdalena Valley montane forests in Colombia, the Bolivian Chaco, and the Brazilian Cerrado. Across these ecoregions, natural habitats are subject to intense and ongoing degradation driven by agricultural expansion, the establishment of monocultures, hydroelectric infrastructure development, and recurrent fire regimes, both natural and intentional. In particular, the humid tropical forests of Colombia exhibit some of the highest deforestation rates worldwide, and the Magdalena Valley forests represent one of the most threatened ecosystems in the country, undergoing rapid landscape transformation despite harboring a high number of endemic and threatened species (Trujillo-Arias et al. 2023).

Given the limited number of localities, the fragmented nature of the known occurrences, and the ongoing degradation of habitats in these ecoregions, we suggest that *P. enteroxanthum* may qualify for a preliminary conservation status of Endangered (EN) B2ab (ii,iii) under IUCN criteria. This classification reflects its small AOO, the reduced number of localities, and an inferred continuous decline in habitat extent and quality due to widespread deforestation, land conversion, and fire regimes in these areas.

This finding also aligns with broader national efforts to close knowledge gaps in fungal diversity and conservation in Brazil. Fungi, including lichens, have historically been overlooked in conservation agendas, but recent initiatives have recognized their ecological importance and the urgent need to incorporate them into biodiversity policies (Drechsler-Santos et al. 2025). Significantly, the first Brazilian lichen species formally assessed for extinction risk, *Parmotrema pachydermum* (Hue) O. Blanco et al., considered Critically Endangered (CR), has already been included in the IUCN Red List of Threatened Species (Spielmann et al. 2022), marking an important step for lichen conservation in the country. Nevertheless, the number of lichenized fungi assessed remains extremely low compared to their actual diversity, largely due to uneven sampling efforts across phytogeographical domains such as the Cerrado, Chaco, and transitional dry forests with rainforests. Documenting new occurrences, such as the present record of *P. enteroxanthum*, is therefore crucial to expand the baseline knowledge needed for future Red List assessments and to strengthen the integration of Brazilian lichen diversity into national and global conservation strategies.

Our record of *P. enteroxanthum* from Maranhão gains further relevance when considered alongside recent discoveries of narrowly distributed *Parmotrema* species in the same Cerrado region. For instance, *Parmotrema*

neoisidiatum I.P.R. Cunha & G.M. Nascim., recently described from southern Maranhão, was preliminarily assessed as Endangered (EN) under IUCN criteria due to its restricted EOO and AOO, combined with ongoing habitat degradation (Nascimento et al. 2025). Together, these findings highlight the Cerrado as both a reservoir of overlooked lichen diversity and a critical biome under severe anthropogenic pressure. Documenting new occurrences and describing endemic taxa are therefore complementary strategies that provide essential data for conservation assessments and for integrating Brazilian lichenized fungi into national and global conservation agendas.

Specimens examined. BRAZIL. Maranhão, Mun. São João do Paraíso: around Itaueiras waterfall, 06°35′18″S, 47°12′27″W, 180 m, 21 Sep. 2018, J.S. Santos and I.P.R. Cunha-Dias 10, 17, 19, 27 (HIMP, BOTU).

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