



Lycophytes and ferns of an Amazonian-Cerrado ecotone in Maranhão State, Northeastern Brazil: identification key and annotated list of taxa

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Abstract: We present a key to identify and an annotated list of lycophytes and ferns of the Immediate Geographical Region of São Luís, Maranhão State, which has ecotonal characteristics of Amazonian Forest, Cerrado, and Coastal Vegetation. Specimens were collected monthly between April 2020 and September 2022 in the 13 municipalities of this region. A total of 64 species were identified, including 61 species of ferns, in 18 families and 38 genera, and three species of lycophytes, in two genera and one family. The most representative families were Pteridaceae (18 species) and Polypodiaceae (nine species). The most recorded substrate of occurrence was terrestrial with 35 species (54.6%), followed by epiphytic with 15 species (23.4%), aquatic with four species (6.2%), rupicolous with three species (4.6%), and hemiepiphytic with two species (3.1%). Five species (7.8%) had more than one life form. This study expands the knowledge about the geographic distribution of fern and lycophyte species in the central region of Northern Maranhão, in Northeastern Brazil, which until now had several sampling gaps. Maranhão has a diversity that is still poorly reported and known compared to other states in South and Southeast Brazil. Therefore, floristic surveys are essential to increase what is known about the flora, especially in areas under anthropic pressure and places with few collections, such as the ecotonal areas in Maranhão.

Keywords: Floristics; Immediate Geographic Region of São Luís; Transition zone.

Licófitas e samambaias de um ecótono Amazonia-Cerrado no estado do Maranhão, Nordeste do Brasil: chave de identificação de lista anotada dos táxons

Resumo: Apresentamos uma chave para a identificação e uma lista com detalhes das licófitas e samambaias da Região Geográfica Imediata de São Luís, Estado do Maranhão, que possui características ecotonais da Floresta Amazônica, Cerrado e Vegetação Litorânea. Os dados foram coletados mensalmente entre abril de 2020 e setembro de 2022 nos 13 municípios dessa região. Foram identificadas 64 espécies, incluindo 61 espécies de samambaias, em 18 famílias e 38 gêneros, e três espécies de licófitas, em dois gêneros e uma família. As famílias mais representativas foram Pteridaceae (18 espécies) e Polypodiaceae (nove espécies). O substrato de ocorrência mais registrado foi o terrestre com 35 espécies (54,6%), seguido do epifítico com 15 espécies (23,4%), aquático com quatro espécies (6,2%), rupícola com três espécies (4,6%) e hemiepifítico com duas espécies (3,1%). Cinco espécies (7,8%) apresentaram mais de uma forma de vida. Este estudo amplia o conhecimento sobre a distribuição geográfica de espécies de samambaias e licófitas na região central do norte do Maranhão, no Nordeste do Brasil, que até então possuía várias lacunas de amostragem. O Maranhão possui uma diversidade ainda pouco relatada e conhecida em comparação com outros estados das regiões Sul e Sudeste do Brasil. Portanto, levantamentos florísticos são essenciais para aumentar o conhecimento sobre a flora, principalmente em áreas sob pressão antrópica e locais com poucas coletas, como as áreas ecotonais do Maranhão.

Palavras-chave: Florística; Região Geográfica Imediata de São Luís; Zona de transição.

Introduction

Lycophytes and ferns are seedless vascular plants that are commonly studied together because they have shared characteristics such as a life cycle with alternation of generations, free gametophytes, and reproduction through spores, have a worldwide distribution, except at the poles, and are very diverse in the tropics (Krieg and Chambers 2022).

In Brazil, 1,412 spp. have been recorded, of which most occur in the Atlantic Forest (944 species), Amazon (578 spp.), and Cerrado (319 spp.) biomes (Ferns and Lycophytes in Flora and Funga of Brazil 2023).

Maranhão is a Brazilian state that has several areas of transitional vegetation, including an ecotonal region between the Amazonian Forest and Cerrado biomes in the central part and, to a lesser extent, an ecotonal region between Cerrado and Caatinga in the eastern part (Spinelli-Araújo et al. 2016). Ecotonal areas between these biomes are floristically diverse due to the numerous habitats in places dominated by Amazonian Forest, Inundated Areas, Mangrove, Restinga, and Cerrado physiognomies (Spinelli-Araújo et al. 2016; Silva-Moraes et al. 2019).

According to the IBGE (2017), Maranhão is divided into five Intermediate Geographic Regions and 22 Immediate Geographic Regions, formerly known as Mesoregions and Microregions, respectively. Among these, the Immediate Geographic Region of São Luís is in a transition area between the Amazon and Cerrado and has a wide variety of water bodies, including the Una, Munim, Arruda, and Boqueirão rivers that have rapids and waterfalls. This area is visited by many tourists and is under high anthropic pressure (Martins 2016).

In the state of Maranhão, the first study of lycophytes and ferns was done by Bastos & Cutrim (1999). They carried out a floristic survey in the Sacavém Forest Reserve in São Luís and reported the occurrence of 35 species, all of which were new records for the state. Subsequent works recorded species already known for the flora of Maranhão, as well as species commonly found in anthropic sites (Conceição & Ruggieri 2010; Conceição et al. 2015; Silva et al. 2017; Silva Junior et al. 2018).

A few surveys were conducted in protected areas, but generally, a low number of species was found (Fernandes et al. 2007, 2010; Conceição & Rodrigues 2010).

According to Flora and Funga of Brazil (2023), 100 species of lycophytes and ferns occur in the state of Maranhão. However, studies of ferns and lycophytes in Maranhão suggest that there is a higher number of species. In a survey conducted only in forest fragments in the Amazonian portion of Maranhão, Silva Junior et al. (2020) reported 64 species, of which 24 were new records for the state. Additionally, in a study in the Chapada das Mesas region, a Cerrado-Amazon transition area, Fernandes et al. (2022) recorded 89 species, 26 of which were also new records for Maranhão. Further, this study provided a compilation of the known species in the state, which resulted in an estimated number of 151 species.

The objective of the present research was to carry out a comprehensive floristic survey of lycophytes and ferns in the thirteen municipalities of the Immediate Geographical Region of São Luís, Maranhão, a transition area between the Amazonian Forest, Cerrado, and Coastal Vegetation biomes and to provide an identification key for all taxa found.

Material and Methods

1. Study area

The state of Maranhão has a tropical rainy climate, AW (humid with moderate water deficit) (Köppen 1948), with an average annual temperature between 25°–26° C and an average annual precipitation between 1,400–1,800 mm; it is one of the northeastern states with the lowest water deficit (Martins & Oliveira 2011). The dry season lasts five to six months, from July to December when there is a water deficit of 150–300 mm (Golfari 1980), and the most intense rainy season is between January and June (Brasil 1986). The Immediate Geographic Region of São Luís (Figure 1) encompasses the Municipalities: of

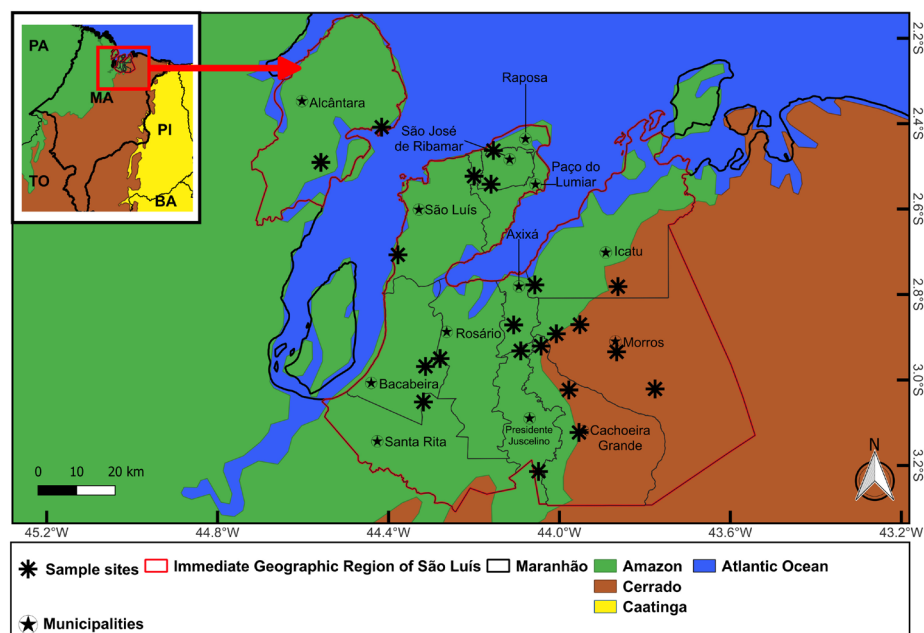


Figure 1. Map of the study area showing the 13 municipalities and the sampling points.

Alcântara, Axixá, Bacabeira, Cachoeira Grande, Icatu, Morros, Paco do Lumiar, Presidente Juscelino, Raposa, Rosário, Santa Rita, São José de Ribamar, and São Luís. It is an area containing predominantly Amazonian Forest vegetation in transition with Coastal Vegetation, with some Cerrado enclaves (Spinelli-Araújo et al. 2016; IBGE 2017).

2. Data collection

Field expeditions were carried out monthly between April 2020 and September 2022. The specimens were georeferenced with a GPS and photographed with a digital camera in the environment where they occurred (Figures 2–4). To locate plants in the field, the free-walking method was used (Filgueiras et al. 1994). Collecting and processing specimens followed standard techniques for vascular plants (Silva 1989; Bridson & Forman 1998).

The material was processed at the Orchid Studies Laboratory at the Federal University of Maranhão, Campus Cidade Universitária Dom Delgado de São Luís, and deposited in the HABIT, SLUI, and SP (acronyms according to Index Herbariorum 2023) herbaria.

Identifications were made using specialized literature (e.g., Tryon & Stolze 1994; Moran & Riba 1995; Mickel & Smith 2004; Prado & Moran 2008; Arantes et al. 2010; Zuquim et al. 2011; Maciel 2016; Prado et al. 2017; Silva et al. 2017; Salino et al. 2018; Prado & Hirai 2020; Silva Junior et al. 2020; Fernandes et al. 2022). The classification of high taxa follows PPG I (2016) and the authors' abbreviations follow the International Plant Names Index (IPNI 2023). The geographical distribution of the species was verified using Flora and Funga of Brazil (2023) and current articles of surveys of fern and lycophyte species in Maranhão (Silva Junior et al. 2020; Fernandes et al. 2022).

The classification of the substrate(s) of occurrence of the taxa found follows Lellinger (2002) and Zuquim et al. (2011), with modifications according to Flora and Funga of Brazil (2023): terrestrial, epiphytic, hemiepiphytic, rupicolous, and aquatic. The environments of occurrence were subdivided into urban, swamp, Cerrado, terra firme Amazonian Forest, free-floating, and gallery forest according to observations made in the field. Table 1 contains the full list of the taxa found, organized by families, genera, and species/varieties, as well as information about the substrate and environment of occurrence, voucher(s) plus an identification key and images of some species/varieties, are also provided. The map of the study area was made using the software QGIS 3.22.14 and SIRGAS 2000 datum and IBGE data (2018).

To recognize the lycophytes and ferns found in this region an identification key is presented and it keys out each taxon at the level of species/varieties. In this work, the data presented in the identification key and Table 1 are complementary since in the Flora and Funga of Brazil (2023) there are no identification keys for families of lycophytes and ferns. The respective family of each taxon belongs can be found in Table 1.

Results

A total of 64 species were recognized, including 61 fern species, in 18 families and 38 genera, and three lycophyte species, in two genera and one family (Table 1). The most recorded substrate was terrestrial with 35 species (54.6%), followed by epiphytic with 15 species (23.4%), aquatic with four species (6.2%), rupicolous with three species (4.6%), and hemiepiphytic with two species (3.1%). Five species (7.8%)

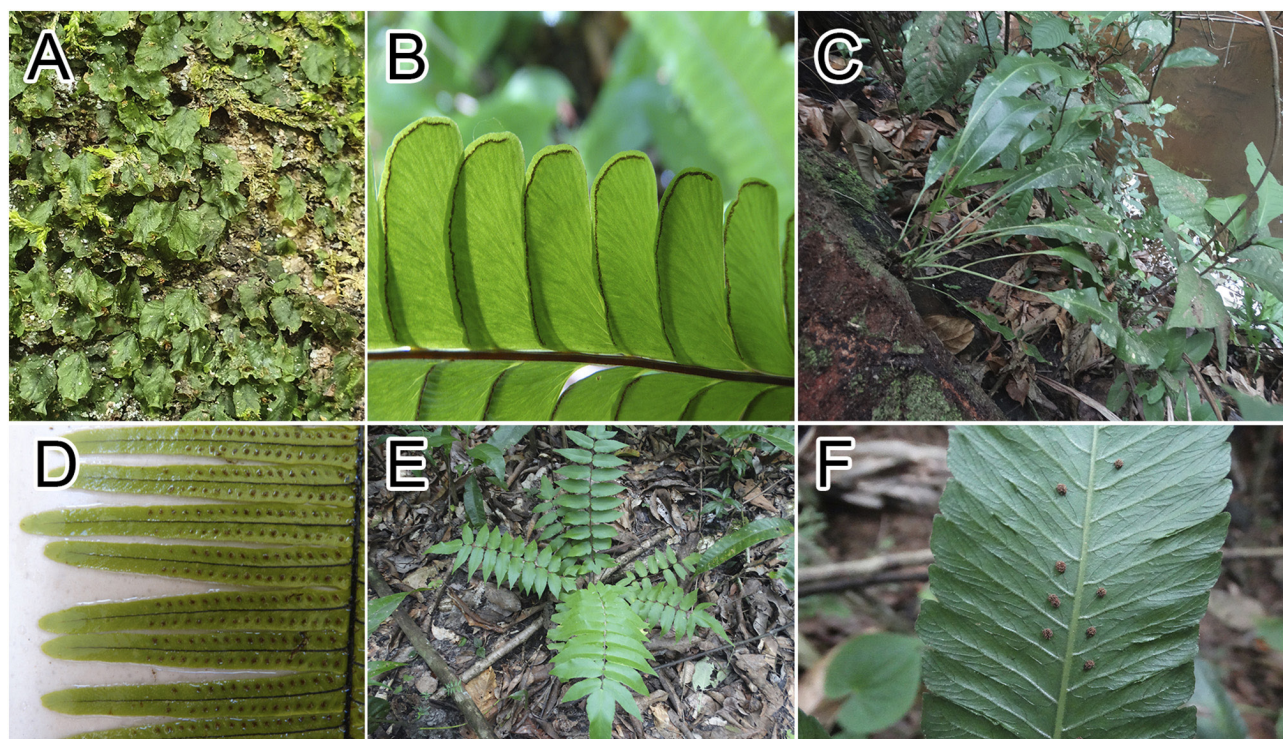


Figure 2. Some species that are new records for Maranhão State. A. *Didymoglossum nummularium*, habit. B. Detail of linear sori of *Lindsaea falcata*. C. *Campyloneurum brevifolium*, habit. D. Detail of sori of *Pecluma plumula*. E. *Hemionitis rufa*, Habit. F. Circular sori and anastomosing veins of *Goniopteris poiteana*.

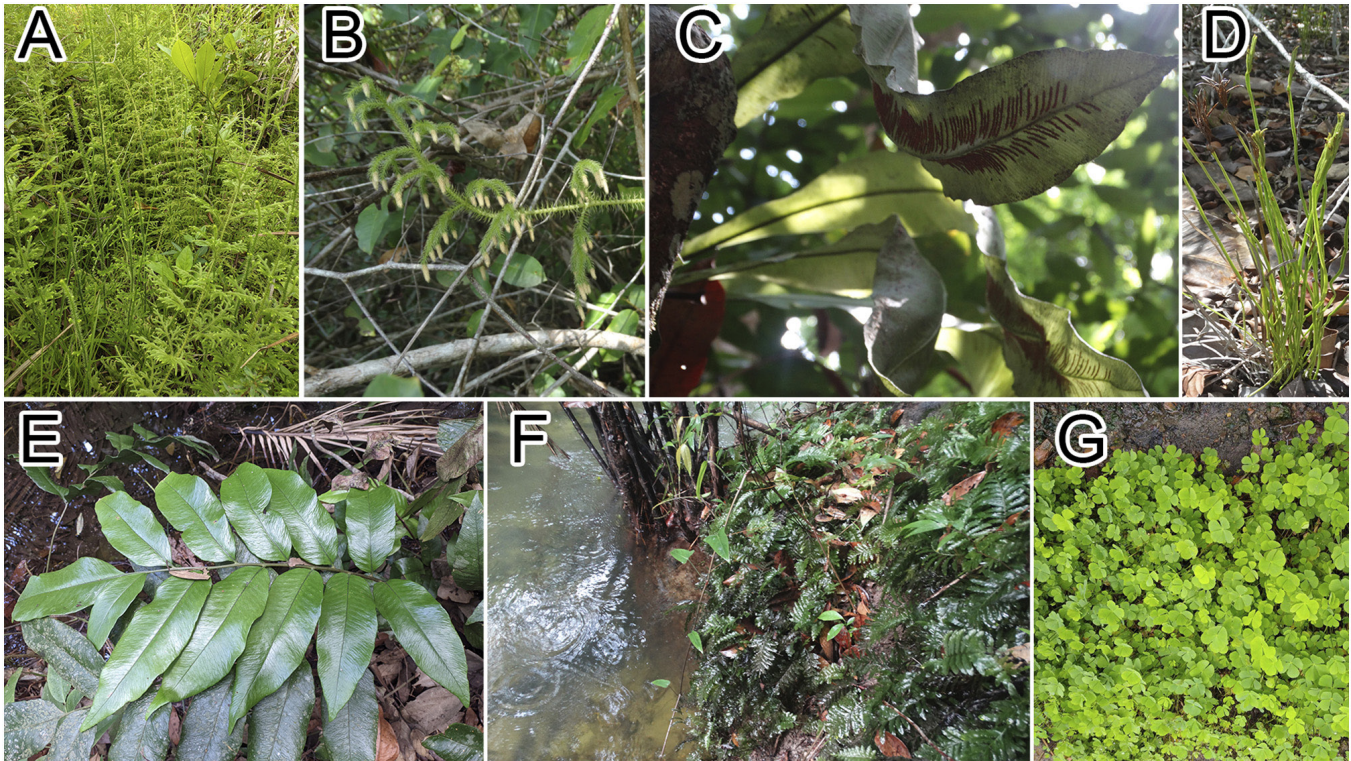


Figure 3. A. *Palhinhaea camporum*, partial view of a population. B. *Palhinhaea cernua*, branches with strobili. C. *Asplenium serratum*, habit. D. *Actinostachys pennula*, habit. E. *Cyclodium meniscioides*, sterile leaf. F. *Trichomanes hostmannianum*, habit, occurring on river margin. G. *Marsilea polycarpa*, partial view of a population.

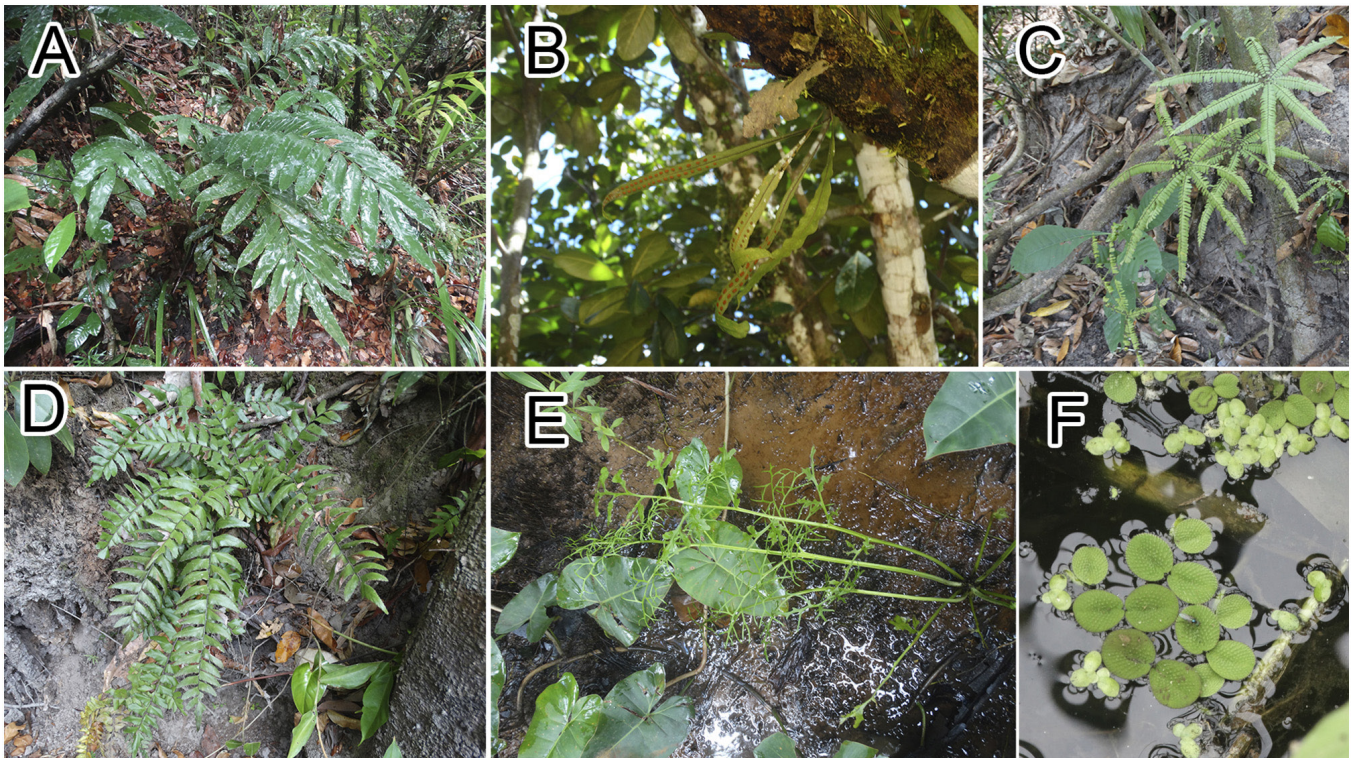


Figure 4. A. *Metaxya parkeri*, habit. B. *Microgramma percussa*, habit. C. *Adiantopsis radiata*, habit. D. *Adiantum latifolium*, habit. E. *Ceratopteris thalictroides*, habit. F. *Salvinia auriculata*, habit (free-floating).

Table 1. Species of lycophytes and ferns in the Immediate Geographic Region of São Luís, their substrates of occurrence, environments of occurrence, collection municipalities, and voucher(s). * = New record for Maranhão State (see Silva Júnior et al. 2023); ** = New records for the Northeast Region of Brazil (see Silva Júnior et al. 2023); SLUI: Rosa Mochel Herbarium.

Taxon	Substrate(s) of occurrence	Environment(s) of occurrence	Municipality(ies)	Voucher(s)/Herbarium/ Number (SLUI)
Lycophytes				
Lycopodiaceae				
<i>Palhinhaea camporum</i> (B.Øllg. & P.G.Windisch) Holub	Terrestrial	Cerrado	Cachoeira Grande Presidente Juscelino Morros São Luís	6850; 6852; 6887; 6907
<i>Palhinhaea cernua</i> (L.) Franco & Vasc.	Terrestrial	Swamp Cerrado	Morros Presidente Juscelino Rosário São Luís	6853; 6888; 6889; 6899
<i>Pseudolycopodiella meridionalis</i> (Underw. & Loyd) Holub	Terrestrial	Cerrado	Cachoeira Grande Morros	6580; 6590
Ferns				
Aspleniaceae				
<i>Asplenium serratum</i> L.	Epiphytic	Gallery forest	Axixá Cachoeira Grande	6873; 6874
Blechnaceae				
<i>Telmatoblechnum serrulatum</i> (Rich.) Perrie, D.J. Ohlsen & Brownsey	Terrestrial	Swamp	Axixá Bacabeira Cachoeira Grande Morros Icatu Presidente Juscelino Raposa Rosário São José de Ribamar São Luís	6592; 6840; 6841; 6843; 6844; 6856; 6857; 6894; 6897; 6910
Cyatheaceae				
<i>Cyathea delgadoi</i> Pohl ex Sternb.	Terrestrial	Gallery forest	Cachoeira Grande	6836
<i>Cyathea microdonta</i> (Desv.) Domin	Terrestrial	Gallery forest	Alcântara Axixá Cachoeira Grande	6596; 6597; 6598; 6828; 6916
Dennstaedtiaceae				
<i>Pteridium esculentum</i> var. <i>harpianum</i> Schwartsb. & A.Yanez	Terrestrial	Cerrado	Cachoeira Grande Morros	6546; 6561; 6591
Dryopteridaceae				
<i>Cyclodium meniscioides</i> (Willd.) C.Presl	Terrestrial	Gallery forest	Axixá Morros	6562; 6579; 6832
Hymenophyllaceae				
<i>Didymoglossum punctatum</i> (Poir.) Desv.	Epiphytic	Gallery forest	Axixá	6583
<i>Didymoglossum nummularium</i> Bosch*	Epiphytic	Gallery forest	Axixá Cachoeira Grande	6582; 6584
<i>Trichomanes hostmannianum</i> (Klotzsch) Kunze	Terrestrial	Gallery forest	Axixá Cachoeira Grande Icatu Morros	6555; 6595; 6817; 6868
<i>Trichomanes pinnatum</i> Hedw.	Terrestrial	Terra Firme Amazonian Forest	Axixá	6848
Lindsaeaceae				
<i>Lindsaea divaricata</i> Klotzsch	Terrestrial	Terra Firme Amazonian Forest	Axixá	6571
<i>Lindsaea falcata</i> Dryand.*	Terrestrial	Gallery forest	Morros	6563

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Taxon	Substrate(s) of occurrence	Environment(s) of occurrence	Municipality(ies)	Voucher(s)/Herbarium/ Number (SLUI)
<i>Lindsaea guianensis</i> Aubl. var. <i>guianensis</i> *	Terrestrial	Gallery forest	Icatu	6551; 6552
<i>Lindsaea pallida</i> Klotzsch	Terrestrial	Gallery forest	Icatu	6556
Lygodiaceae				
<i>Lygodium venustum</i> Sw.	Hemiepiphytic	Urban environment Cerrado	Alcântara Axixá Cachoeira Grande Paço do Lumiar Rosário Santa Rita São José de Ribamar	6814; 6863; 6864; 6903; 6909; 6918; 6919
<i>Lygodium volubile</i> Sw.	Hemiepiphytic	Cerrado Terra Firme Amazonian Forest	Axixá Cachoeira Grande	6829; 6830
Marsileaceae				
<i>Marsilea polycarpa</i> Hook. & Grev.	Aquatic	Urban environment	Alcântara São José de Ribamar	6913; 6914
Metaxyaceae				
<i>Metaxya parkeri</i> (Hook. & Grev.) J.Sm.	Terrestrial	Gallery forest	Morros	6566
Nephrolepidaceae				
<i>Nephrolepis biserrata</i> (Sw.) Schott	Epiphytic Terrestrial	Urban environment Swamp Cerrado Terra Firme Amazonian Forest	Alcântara Axixá Bacabeira Cachoeira Grande Icatu Paço do Lumiar Presidente Juscelino Raposá Rosário Santa Rita São José de Ribamar São Luís	6820; 6821; 6823; 6824; 6846; 6847; 6855; 6858; 6865; 6866; 6878; 6879; 6880; 6890; 6896; 6901; 6902
<i>Nephrolepis brownii</i> (Desv.) Hovenkamp & Miyam	Terrestrial	Swamp Terra Firme Amazonian Forest	Cachoeira Grande São Luís	6904; 6905
Polypodiaceae				
<i>Campyloneurum brevifolium</i> (Link) Link**	Epiphytic	Gallery forest	Axixá	6569
<i>Campyloneurum phyllitidis</i> (L.) C. Presl	Epiphytic	Terra Firme Amazonian Forest	Cachoeira Grande	6895
<i>Microgramma lycopodioides</i> (L.) Copel.	Epiphytic	Gallery forest	Rosário	6831
<i>Microgramma percussa</i> (Cav.) de la Sota	Epiphytic	Terra Firme Amazonian Forest	Axixá Bacabeira	6553; 6560; 6842
<i>Microgramma persicariifolia</i> (Schrad.) C.Presl	Epiphytic Rupicolous Terrestrial	Terra Firme Amazonian Forest	Axixá Cachoeira Grande	6837; 6839
<i>Pechuma plumula</i> (Willd.) M.G.Price*	Epiphytic	Gallery forest	Cachoeira Grande	6544; 6545
<i>Phlebodium aureum</i> (L.) J.Sm.	Epiphytic	Urban environment Terra Firme Amazonian Forest	Alcântara Axixá Bacabeira Cachoeira Grande Icatu Presidente Juscelino	6849; 6854; 6875; 6876; 6877; 6912

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Taxon	Substrate(s) of occurrence	Environment(s) of occurrence	Municipality(ies)	Voucher(s)/Herbarium/ Number (SLUI)
<i>Phlebodium decumanum</i> (Willd.) J.Sm.	Epiphytic	Urban environment Terra Firme Amazonian Forest	Bacabeira Paço do Lumiar Presidente Juscelino Raposa Rosário Santa Rita São José de Ribamar São Luís	6833; 6834; 6859; 6860; 6861; 6862; 6891; 6892
<i>Serpocaulon triseriale</i> (Sw.) A.R.Sm.	Epiphytic	Terra Firme Amazonian Forest	Axixá	6548; 6570
Psilotaceae				
<i>Psilotum nudum</i> (L.) P. Beauv.	Rupicolous	Urban environment	São Luís	6921
Pteridaceae				
<i>Acrostichum aureum</i> L.	Terrestrial	Mangroves	Axixá	6886
<i>Acrostichum danaeifolium</i> Langsd. & Fisch.	Terrestrial	Swamp	Axixá Morros São José de Ribamar	6883; 6884; 6885
<i>Adiantopsis radiata</i> (L.) Fée	Terrestrial	Gallery forest	Icatu	6554
<i>Adiantum deflectens</i> Mart.	Rupicolous Terrestrial	Urban environment	Alcântara	6920
<i>Adiantum dolosum</i> Kunze	Terrestrial	Terra Firme Amazonian Forest	Axixá	6549
<i>Adiantum latifolium</i> Lam.	Terrestrial	Terra Firme Amazonian Forest	Axixá Cachoeira Grande Rosário Santa Rita	6550; 6565; 6585; 6851; 6872
<i>Adiantum pulverulentum</i> L.	Terrestrial	Terra Firme Amazonian Forest	Axixá	6576
<i>Adiantum terminatum</i> Kunze ex Miq.	Terrestrial	Terra Firme Amazonian Forest	Cachoeira Grande	6593; 6594; 6908
<i>Ananthacorus angustifolius</i> (Sw.) Underw. & Maxon	Epiphytic	Terra Firme Amazonian Forest	Axixá	6819
<i>Ceratopteris thalictroides</i> (L.) Brongn.	Aquatic	Urban environment Gallery forest	Cachoeira Grande São José de Ribamar	6870; 6871
<i>Hemionitis rufa</i> (L.) Sw.**	Rupicolous Terrestrial	Terra Firme Amazonian Forest Gallery forest	Axixá Cachoeira Grande	6564; 6838
<i>Pityrogramma calomelanos</i> (L.) Link	Rupicolous Terrestrial	Urban environment, Swamp Gallery forest	Alcântara Axixá Icatu Morros Paço do Lumiar, Santa Rita	6815; 6816; 6881; 6882; 6906; 6917
<i>Polytaenium citrifolium</i> (L.) Schuettp.*	Epiphytic	Gallery forest	Cachoeira Grande	6558
<i>Polytaenium guayanense</i> (Hieron.) Alston	Epiphytic	Gallery forest	Cachoeira Grande	6572
<i>Pteris ensiformis</i> Burm.f.*	Rupicolous	Urban environment Gallery forest	Presidente Juscelino, São José de Ribamar	6867; 6893
<i>Pteris tripartita</i> Sw.	Terrestrial	Urban environment Swamp	Cachoeira Grande	6869; 6922
<i>Pteris vittata</i> L.	Rupicolous	Urban environment	Alcântara	6911
<i>Vittaria lineata</i> (L.) Sm.	Epiphytic	Terra Firme Amazonian Forest	Axixá Bacabeira Cachoeira Grande São Luís	6586; 6845; 6898; 6900

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Taxon	Substrate(s) of occurrence	Environment(s) of occurrence	Municipality(ies)	Voucher(s)/Herbarium/ Number (SLUI)
Salviniaceae				
<i>Salvinia auriculata</i> Aubl.	Aquatic	Free-floating	São José de Ribamar	6557
<i>Salvinia radula</i> Baker	Aquatic	Free-floating	Alcântara Santa Rita	6588; 6915
Schizaeaceae				
<i>Actinostachys pennula</i> (Sw.) Hook.	Terrestrial	Cerrado	Icatu Morros	6581; 6818
<i>Schizaea elegans</i> (Vahl) Sw.	Terrestrial	Terra Firme Amazonian Forest	Morros	6589
Tectariaceae				
<i>Tectaria incisa</i> Cav.	Terrestrial	Terra Firme Amazonian Forest River margin Gallery forest	Axixá	6577
<i>Triplophyllum funestum</i> (Kunze) Holttum	Terrestrial	Gallery forest	Axixá	6559; 6575
Thelypteridaceae				
<i>Christella hispidula</i> (Decne) Holttum	Terrestrial	Gallery forest	São Luís	6567
<i>Cyclosorus interruptus</i> (Willd.) H.Itô	Terrestrial	Cerrado	Axixá	6587; 6835
<i>Goniopteris poiteana</i> (Bory) Ching*	Terrestrial	Terra Firme Amazonian forest	Axixá	6573
<i>Goniopteris tristis</i> (Kunze) Brade**	Terrestrial	Terra Firme Amazonian forest	Axixá	6547; 6574
<i>Macrothelypteris torresiana</i> (Gaud.) Ching	Terrestrial	Gallery forest	São Luís	6568
<i>Meniscium hostmannii</i> (Klotzsch) R.S.Fern. & Salino	Terrestrial	Swamp	Cachoeira Grande	6822
<i>Meniscium serratum</i> Cav.	Terrestrial	Swamp	Axixá Cachoeira Grande Icatu	6825, 6826; 6827

occurred in more than one type of substrate, terrestrial/rupicolous and epiphytic/terrestrial, and one species colonized three types of substrates: epiphytic, terrestrial, and rupicolous (see Table 1).

The Municipalities with the highest number of species were Axixá (32 spp.), Cachoeira Grande (27 spp.), and Morros (12 spp.), while the municipalities with the lowest number of species were Paço do Lumiar (4 spp.) and Raposa (3 spp.) (see Table 1). Although this region is an Amazonian-Cerrado ecotone, most of the species are Amazonian since they are associated with the vegetation close to the watercourses in these municipalities.

Each taxon from the studied region can be identified at the level of genus, species, and/or variety using the key below, and its respective family, plus other information, can be found in Table 1.

Identification key to the lycophyte and fern species in the Immediate Geographic Region of São Luís

1. Plant leaves microphylls (with one medial vein), acicular2
 1. Plant leaves megaphylls (complex venation), simple (entire), decomposed (pinnate or more divided), or scale-like 4
2. Plants prostrate, strobili erect
 - *Pseudolycopodiella meridionalis*
 2. Plants erect, strobili pendant 3
3. Microphylls densely arranged; lateral branches ascending or suberect
 - *Palhinhaea camporum* (Fig. 3A)
 3. Microphylls sparse; lateral branches recurved downward *Palhinhaea cernua* (Fig. 3B)
4. Leaves scale-like; sporangia fused, forming a synangium
 - *Psilotum nudum*
 4. Leaves simple or decomposed; sporangia not fused, grouped in sori, sporocarps, or spikes 5
5. Plants arborescent 6
 5. Plants herbaceous 7
6. Sori with globose indusia *Cyathea delgadoi*
6. Sori lacking indusia *Cyathea microdonta*
7. Lamina translucent, thin, with one or two layers of cells; stomata absent; sporangia with oblique annulus 8
 7. Lamina not translucent, with several layers of cells; stomata present; sporangia with apical or longitudinal annulus, or the annulus consisting of a slightly thickened lateral patch 11
8. Leaves entire, <3 cm long; true roots absent; false veinlets present in the lamina parallel to the true veins 9
 8. Leaves pinnate, >3 cm long; true roots present; false veinlets absent or, when present, perpendicular to the true veins 10

9. Leaves with palmate venation; margin of the indusium without darkened cells *Didymoglossum nummularium* (Fig. 2A)
9. Leaves with flabellate venation; margin of the indusium with darkened cells *Didymoglossum punctatum*
10. Lamina lacking false veinlets *Trichomanes hostmannianum* (Fig. 3F)
10. Lamina with false veinlets, these perpendicular to the true veins *Trichomanes pinnatum*
11. Plants aquatic, fixed to a substrate or free-floating 12
11. Plants terrestrial, epiphytic, hemiepiphytic, or rupicolous 15
12. Plants aquatic, with roots fixed to a substrate 13
12. Plants aquatic, free-floating 14
13. Lamina 4-foliolate; sporangia generally between 5–20, grouped into sporocarps *Marsilea polycarpa* (Fig. 3G)
13. Lamina 1–3-pinnate; sporangia numerous >20, grouped into grooves on lamina margins *Ceratopteris thalictroides* (Fig. 4E)
14. Adaxial surface of the floating lamina with conspicuous papillae; apex of lamina slightly incised *Salvinia auriculata* (Fig. 4F)
14. Adaxial surface of the floating lamina with minute papillae or papillae absent; apex of lamina round *Salvinia radula*
15. Sporangia sessile; annulus not interrupted by the pedicel of the sporangium, apical to subapical, or oblique 16
15. Sporangia pedicellate; annulus interrupted by the pedicel of the sporangium 20
16. Sporangia with oblique annulus *Metaxya parkeri* (Fig. 4A)
16. Sporangia with apical to subapical annulus 17
17. Plants with indefinite growth, reaching several meters long, scandent/climbing 18
17. Plants with defined growth, reaching up to 50 cm long 19
18. Pinnules continuous with the petiolule *Lygodium venustum*
18. Pinnules articulate with the petiolule *Lygodium volubile*
19. Leaves with dichotomously divided or flabellate lamina *Schizaea elegans*
19. Leaves with linear lamina *Actinostachys pennula* (Fig. 3D)
20. Petiole articulate with the rhizome 21
20. Petiole continuous with the rhizome 29
21. Leaves with 1-pinnate or pinnatisect lamina 22
21. Leaves with simple lamina 25
22. Lamina 1-pinnate; rachis not sulcate adaxially *Pechuma plumula* (Fig. 2D)
22. Lamina pinnatisect; rachis sulcate adaxially 23
23. Sorus borne on a receptacle formed on the tip of the single veinlet included in the areole *Serpocaulon triseriale*
23. Sorus borne on a receptacle formed on the tips of two parallel veinlets in the areole 24
24. Sori distributed in two rows between the margin and costa of the segments *Phlebodium aureum*
24. Sori distributed in more than two rows between the margin and costa of the segments *Phlebodium decumanum*
25. Rhizomes short-creeping, with clathrate scales; sori arranged in two or more rows between the costa and margin of the lamina 26
25. Rhizomes long-creeping, scales not clathrate; sori arranged in only one row between the costa and margin of the lamina 27
26. Areoles in 8–18 rows between the costa and margin of the lamina *Campyloneurum brevifolium* (Fig. 2C)
26. Areoles in 7–8 rows between the costa and margin of the lamina *Campyloneurum phyllitidis*
27. Sori varying from round to oblong *Microgramma persicariifolia*
27. Sori round 28
28. Lamina venation visible adaxially; rhizome scales with ciliate margins *Microgramma lycopodioides*
28. Lamina venation not visible adaxially; rhizome scales with dentate margins *Microgramma percussa* (Fig. 4B)
29. Sori pseudoacrostichoid or totally acrostichoid 30
29. Sori marginal, submarginal, or between the veins 33
30. Venation reticulate, areoles irregular to round, without included veinlets 31
30. Venation areolate, areoles regular, in pairs, with the transverse veins producing excurrent veins that run toward the margin of the leaf 32
31. Sori present along all pinnae of the fertile fronds *Acrostichum danaeifolium*
31. Sori present only on the distal pinnae of the fertile fronds *Acrostichum aureum*
32. Pinnae with serrate margins; sporangia glabrous *Meniscium serratum*
32. Pinnae with crenulate margins; sporangia with paraphyses on the pedicel *Meniscium hostmannii*
33. Rhizome scales clathrate 34
33. Rhizome scales not clathrate 38
34. Sori with indusia *Asplenium serratum* (Fig. 3C)
34. Sori lacking indusia 35
35. Sori submarginal, parallel to the margin of the lamina 36
35. Sori arranged along the laminar tissue abaxially on the veins or between the veins 37
36. Leaves linear (2–3 mm wide), with one row of areoles between the costa and margin of the lamina *Vittaria lineata*
36. Leaves linear-elliptic (0.8–1.5 cm wide), with two to five rows of areoles between the costa and margin of the lamina *Ananthacorus angustifolius*
37. Rhizomes long-creeping; leaves elliptic; sori on and between veins *Polytaenium citrifolium*
37. Rhizomes short-creeping; leaves oblanceolate; sori only on veins *Polytaenium guayanense*
38. Base of the petiole (cross-section) with two vascular bundles 39
38. Base of the petiole (cross-section) with one, three, or more vascular bundles 43

39. Leaves 2-pinnate-pinnatifid; costa without grooves adaxially *Macrothelypteris torresiana*
 39. Leaves 1-pinnate-pinnatifid; costa sulcate adaxially 40
40. Furcate or stellate hairs present on the rachis and scales of the rhizome 41
 40. Furcate or stellate hairs absent on the rachis and scales of the rhizome 42
41. Venation free; sporangia glabrous *Goniopteris tristis*
 41. Venation anastomosing; sporangia with setiform hairs
 *Goniopteris poiteana* (Fig. 2F)
42. Rhizomes short-creeping; petiole and rachis pubescent
 *Christella hispida*
42. Rhizomes long-creeping; petiole and rachis glabrous
 *Cyclosorus interruptus*
43. Sori linear, borne on the two sides of the costa; indusium opening introrsely *Telmatoblechnum serrulatum*
 43. Sori round to linear, borne in a submarginal or median position on the lamina; indusium absent, present and opening extrorsely, or a false indusium present and formed by a revolute, modified (thin) lamina margin 44
44. Sori with reniform indusium 45
 44. Sori indusium several shapes (not reniform) or false indusium present and formed by a revolute, modified (thin) lamina margin 46
45. Scales on the petiole base bicolor (blackish and light brown), with ciliate margins; sori submarginal *Nephrolepis brownii*
 45. Scales on the petiole base concolor (orangish), with entire margins; sori median *Nephrolepis biserrata*
46. Sterile and fertile leaves dimorphic; sterile pinnae lanceolate and fertile pinnae linear *Cyclodium meniscioides* (Fig. 3E)
 46. Sterile and fertile leaves monomorphic 47
47. Sori circular, protected by a true indusium (formed abaxially) 48
 47. Sori linear, circular to oblong, covered by a true indusium or by a false indusium formed by a revolute, modified (thin) lamina margin 49
48. Rhizomes erect; veins anastomosing; indusium glabrous
 *Tectaria incisa*
48. Rhizomes creeping; veins free; indusium pubescent
 *Triplophyllum funestum*
49. Leaves more than 1.5 m long; lamina coriaceous
 *Pteridium esculentum* var. *harpianum*
49. Leaves up to 1 m long; lamina chartaceous or membranaceous 50
50. Indusia present, linear, abaxial 51
 50. Indusia absent or with marginal false indusia 54
51. Petiole alate; terminal pinna with non-prolonged apex 52
 51. Petiole not alate; terminal pinna with prolonged apex 53
52. Laminae 2-pinnate; rachis reddish brown
 *Lindsaea divaricata*
52. Laminae 1-pinnate; rachis paleaceous to dark brown
 *Lindsaea falcata* (Fig. 2B)
53. Rhizomes long-creeping; apical pinnule with entire margins
 *Lindsaea guianensis* var. *guianensis*
53. Rhizomes short-creeping; apical pinnule with crenulate to serrate margins *Lindsaea pallida*
54. Indusia absent 55
 54. False indusia marginal 56
55. Laminae 2-pinnate-pinnatifid; rachis glabrous; lamina with whitish farina abaxially *Pityrogramma calomelanos*
 55. Laminae 1-pinnate; rachis pubescent; lamina without whitish farina abaxially *Hemionitis rufa* (Fig. 2E)
56. Sporangia borne on the abaxial surface of the lamina and protected by a false indusium that lacks veins; sori with paraphyses or not 57
 56. Sporangia borne on the adaxial surface of a revolute lamina margin, forming a false indusium with veins 60
57. Sori without paraphyses *Adiantopsis radiata* (Fig. 4C)
 57. Sori with paraphyses 58
58. Laminae variegated on the adaxial surface, with whitish details
 *Pteris ensiformis*
58. Laminae not variegated 59
59. Laminae 1-pinnate; veins free *Pteris vittata*
 59. Laminae 2-pinnate-pinnatifid; veins partially areolate
 *Pteris tripartita*
60. Laminae 1-pinnate 61
 60. Laminae 2-pinnate 62
61. Pinnae flabellate; veins free *Adiantum deflectens*
 61. Pinnae lanceolate; veins irregularly anastomosing
 *Adiantum dolosum*
62. Rhizomes, petioles, and rachis completely covered with scales; sori 1 or 2(3) per pinnule *Adiantum pulverulentum*
 62. Rhizomes, petioles, and rachis with sparse scales; sori more than 3 per pinnule 63
63. Laminae glabrous abaxially; false indusium glabrous
 *Adiantum latifolium* (Fig. 4D)
 63. Laminae with septate hairs abaxially; false indusium with septate hairs *Adiantum terminatum*

Discussion

The total number of fern and lycophyte species collected during this survey was 41.7% of the species recorded for the state of Maranhão (Silva Junior et al. 2020; Fernandes et al. 2022; Flora and Funga of Brazil 2023). It is the third largest study in number of taxa recorded for Maranhão State (Figures 3 and 4).

Some taxa presented in this study represent new records for Maranhão State or new records for the Northeast Region of Brazil. These novelties are highlighted in Table 1 with one or two stars, respectively. Although this list is similar to the list presented by Silva Junior et al. (2023) these results were not previously highlighted by the authors as being new records. Additionally, in the present list, *Adiantopsis radiata* (L.) Fée is another novelty not previously recorded by Silva Junior et al. (2023).

The first study to record fern species in the Immediate Geographic Region of São Luís was presented by Bastos & Cutrim (1999). It was conducted in Sacavém Park in São Luís. Although the present study was not carried out in the same place as Bastos & Cutrim (1999), we found all the species reported by them in other parts of the study area, except for *Adiantum raddianum* C.Presl and *Lindsaea stricta* (Sw.) Dryand. Another study that recorded fern species in the study region is Silva Junior et al. (2018), who reported the occurrence of *Pteris tripartita* Sw.

(an introduced fern species in Brazil) in the municipality of São José de Ribamar. In the present study, this species was also collected in the municipality of São Luís.

The most representative family was Pteridaceae with 17 species, which was also reported in two other studies carried out in Maranhão, one in areas of the Amazonian Forest (Silva Junior et al. 2020) and another in areas of Cerrado (Fernandes et al. 2022). The family Pteridaceae is one of the most diverse in Brazil and their genera have wide geographic distribution, because of it, it has been reported as one of the commonest in studies of ferns in Brazil (e.g., Maciel & Pietrobom 2010; Winter et al. 2011; Miranda et al. 2015; Menezes & Labiak 2020; Silva Junior et al. 2020; Fernandes et al. 2022; Flora and Funga of Brazil 2023).

Adiantum (Pteridaceae) had the highest number of species (five). This was expected since it has species that colonize various environments and is often the most diverse genus in studies that report the occurrence of Pteridaceae (Maciel & Pietrobom 2010; Winter et al. 2011; Miranda et al. 2015; Silva Junior et al. 2020; Oliveira et al. 2021; Fernandes et al. 2022).

Another genus of Pteridaceae that exhibited peculiarities in the study area was *Acrostichum* L. because its two species occur in different environments. *Acrostichum aureum* occurs exclusively in coastal areas and is associated mainly with mangroves, while *A. danaeifolium* was observed in swamps that were further away from coastal vegetation.

The second most representative family was Polypodiaceae, with nine taxa. Polypodiaceae are poorly represented in inventories of ferns that have been carried out in Maranhão (Silva Junior et al. 2020; Fernandes et al. 2022). However, the number of new records of this family is increasing for the state as revealed by Silva Junior et al. (2020).

The municipalities of Axixá, Cachoeira Grande, and Morros had the highest number of fern and lycophyte species. This is probably because they have several water bodies, such as swamps and tributaries of the Munim River, as well as upland and gallery forests with continuous vegetation and greater humidity throughout the year, which favor the physiology and reproduction of ferns. On the other hand, in the municipalities with the fewest species (Paço do Lumiar and Raposa) there are not many areas with native vegetation due to a greater amount of urbanization.

In the study region, only three fern species occurred specifically in the Cerrado vegetation: *Actinostachys pennula* (Sw.) Hook., *Pteridium esculentum* var. *harpiantum*, and *Schizaea elegans* (Vahl) Sw. This vegetation has a dry period between July and December, showing that these species are more tolerant to water stress. The three species of lycophytes occurred in swampy areas and *veredas*, which are sunny and humid environments throughout the year. However, it was noted that *Pseudolycopodiella meridionalis* (Underw. & Loyd) Holub is less common than the other two species of lycophytes.

The most observed species in the study area were *Nephrolepis biserrata* (Sw.) Schott, *Phlebodium decumanum* (Willd.) J.Sm., and *Telmatoblechnum serrulatum* (Rich.) Perrie, D.J.Ohlsen & Brownsey, which occur in more than eight municipalities. *Nephrolepis biserrata* was observed mainly as epiphytic or rupicolous. *Pteris ensiformis* Burm. f. was found in three municipalities in the study area. It is native to Asian countries and considered naturalized in Brazil. Its main use is for ornamental purposes due to its variegated leaves (Costa et al. 2020; Freitas et al. 2021). *Macrothelypteris torresiana* (Gaud.) Ching

is also naturalized and widely distributed in Brazil (Hirai et al. 2016). Exotic species of ferns are commonly recorded in natural areas in the state of Maranhão (Silva Junior et al. 2018; Silva Junior et al. 2020), indicating human influence and the need for environmental monitoring because exotic fern species can negatively affect the native flora (Silva Junior et al. 2018).

This set of data from the Immediate Geographical Region of São Luís was the subject of some floristic similarity analysis by Silva Junior et al. (2023). In this similarity study, the species found were mostly Amazonian. The prevalence of Amazonian species is probably because ferns and lycophytes mostly occur in wet environments. In the Cerrado, the effect of the dry season is more noticeable than in the Amazonia, which makes it difficult for ferns and lycophytes to colonize. Even in Cerrado areas in Maranhão, most species occur in gallery forests, which have a more humid environment throughout the year (Silva Junior et al. 2023).

Conclusion

This study increased what is known about the composition of fern and lycophyte flora in the central region of Northern Maranhão, which was a poorly known area. Maranhão has an extensive ecotonal zone between the Amazon and Cerrado biomes, and there is a lack of studies of lycophytes and ferns in this region. The number of records of these plants is constantly increasing in Maranhão (Silva Junior et al. 2020; Fernandes et al. 2022; Silva Júnior et al. 2023), as seen by the results of this study. This mosaic of biomes promotes a variety of environments conducive to the propagation of lycophytes and ferns that need to be studied before they disappear.

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Conflicts of Interest

All authors have seen and agree with the contents of the manuscript and there is no conflict of interest, including financial interest, relationships, and affiliations relevant to the subject of the manuscript.

Data Availability

Supporting data are available at <<https://data.scielo.org/dataset.xhtml?persistentId=doi:10.48331/scielodata.PWYWNZ>>.

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