



Original Papers

Floristic diversity of an urban protected area of Atlantic Forest in Northeast Brazil: Dois Irmãos State Park, Pernambuco

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Abstract

A floristic inventory was prepared for the Dois Irmãos State Park (PEDI, Recife, PE, Brazil), one of the most significant Atlantic Forest remnants (1,158 hectares) and an essential urban protected area in the Brazilian Northeast. The inventory included monthly field collections (2014–2015, 2017–2018) in a PPBio Program RAPELD module, searches in the INCT - Virtual Herbarium and literature, followed by a careful taxonomic review, including avascular and vascular plants. Species were assigned to a category for their habitats, habits, life forms, origin, extinction risk status, and substrate type. Overall, 992 species were registered (515 genera, 140 families). The Angiosperms comprised 887 species (110 families), of which 65% were woody species: 370 (41.7%) trees, six palm trees (0.7%), 146 (16.5%) shrubs, 56 (6.3%) climbers; and 309 (35%) were herbaceous plants. The most important angiosperm families were Fabaceae (90 species), Poaceae (54 spp.), Rubiaceae (47 spp.), Myrtaceae (35 spp.), Cyperaceae and Melastomataceae (32 spp. each). Forty-four species of ferns and lycophytes (15 families) were recorded; Pteridaceae (12 spp.), Thelypteridaceae (6 spp.), and Polypodiaceae (5 spp.) were the richest. We registered 61 species (14 families) of avascular plants, of which Lejeuneaceae (23 spp.), Calymperaceae (9 spp.) and Sematophyllaceae (7 spp.) exhibited the highest richness. We found 13 threatened species, such as *Canistrum aurantiacum* (Bromeliaceae) and *Ocotea odorifera* (Lauraceae). Our results confirm that the PEDI holds a high floristic richness in comparison to other checklists from this Atlantic Forest region. This highlights the importance of the Dois Irmãos State Park as a unique and valuable natural resource, and the need for more conservation efforts to protect this area.

Key words: checklist, floristic richness, inventory, PPBio.

Resumo

Neste trabalho, foi compilada a lista florística do Parque Estadual de Dois Irmãos (PEDI, Recife, PE, Brasil), um dos mais significativos remanescentes de Mata Atlântica (1.158 ha) do Nordeste brasileiro e uma importante área protegida urbana. O inventário incluiu coletas de campo mensais (2014–2015, 2017–2018) em um módulo RAPELD do Programa PPBio, além de consulta ao INCT - Herbário Virtual e pesquisa bibliográfica, seguida de criteriosa revisão taxonômica, e incluiu plantas não vasculares e vasculares. As espécies foram classificadas de acordo com os seus habitats, hábitos, formas de vida, origem, risco de extinção, e tipo de substrato. No total, foram registradas 992 espécies (515 gêneros, 139 famílias). Nas Angiospermas, foram encontradas 887 espécies (110 famílias), entre as quais 65% de espécies lenhosas: 370 (41,7%) árvores, seis palmeiras (0,7%), 145 (16,5%) arbustos, 56 (6,3%) trepadeiras; 309 (35%) foram plantas herbáceas. As famílias mais importantes de angiospermas foram Fabaceae (90 espécies), Rubiaceae (47 spp.), Poaceae (54 spp.),

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Myrtaceae (35 spp.), Cyperaceae e Melastomataceae (32 spp.). Foram registradas 44 espécies de samambaias e licófitas (15 famílias), sendo Pteridaceae (12 spp.), Thelypteridaceae (6 spp.) e Polypodiaceae (5 spp.) as mais ricas. Registraram-se 61 espécies (14 famílias) de plantas avasculares, entre as quais Lejeuneaceae (23 spp.), Calymperaceae (10 spp.) e Sematophyllaceae (7 spp.) apresentaram a maior riqueza. Houve ocorrência de 13 espécies ameaçadas, como *Canistrum aurantiacum* (Bromeliaceae) e *Ocotea odorifera* (Lauraceae). Os resultados confirmam que o PEDI possui uma alta riqueza em comparação com outras listas florísticas na região da Mata Atlântica. Isso reforça a importância do Parque Estadual de Dois Irmãos como um recurso natural único e valioso e a necessidade de mais esforços de conservação para proteção efetiva da área.

Palavras-chave: checklist, riqueza florística, inventário, PPBio.

Introduction

The Atlantic Forest has been recognised for decades as one of the regions with the most extraordinary biodiversity and endemism on the planet (Myers *et al.* 2000). Along with its high endemism (> 1,500 endemic species), the region has experienced extreme habitat destruction over the past few centuries. These two characteristics make the Atlantic Forest one of the 36 hotspots for conservation priorities (Mittermeier *et al.* 2011). Together, all the hotspots house more than 152,000 plant species as single-hotspot endemics, or around 41% of the world's total species, as reported by Christenhusz & Byng (2016).

According to the last effort to map the Atlantic Forest in detail (Rezende *et al.* 2018), 28% of native vegetation remains in the biome, including forests in late or intermediate successional stages and non-forest areas predominantly composed of shrubs and grassland. Built-up areas, large dams, forestry and anthropic spaces now occupy 82% of the previously forested habitats. Despite the intense forest reduction and fragmentation in recent centuries (Joly *et al.* 2014), the Atlantic Forest is home to nearly 18,200 plant species, of which 48% represent single-biome endemics (Flora e Funga do Brasil 2023, continuously updated), and 2,420 animal species (Joly *et al.* 2019). On the other hand, many species are at risk of extinction and included on the red list of threatened species, of which 1,544 are Atlantic Forest plant species (Paglia *et al.* 2008; Martinelli & Moraes 2013; Joly *et al.* 2019).

Following the division of the biome into Biogeographic Subregions - BSR (Silva & Casteleti 2005), the northernmost region of the Atlantic Forest, known as the Pernambuco Endemism Center (PEC), is the portion most critically threatened by anthropogenic factors, such as reduction, fragmentation, disturbance and urbanisation (Mori *et al.* 1981; Ranta *et al.* 1998;

Myers *et al.* 2000; Trindade *et al.* 2008). After four waves of fragmentation over five centuries, forest cover has been reduced to only 13% in the region (Lins-e-Silva *et al.* 2021), most fragments are smaller than 50 ha, none exceed 10,000 ha, and less than 1% is strictly protected (Ribeiro *et al.* 2009). Extinction of species and shifts in the ecological profiles of plant assemblages are of more concern in the PEC than in any other region of the biome (Silva & Casteleti 2005; Joly *et al.* 2014). Only 23 remnants in the PEC are larger than 1,000 ha (Mendes Pontes *et al.* 2016), of which very few are officially protected, such as the Dois Irmãos State Park (Parque Estadual de Dois Irmãos, PEDI, 1158 ha, object of this study).

The maintenance of large forest patches is crucial for biodiversity conservation. There is higher habitat diversity and fewer areas under edge effects in larger fragments, where more species are expected (Ewers & Didham 2006; Tschardtke *et al.* 2012). This pattern is particularly true for plant assemblages when data are collected from fragments of various sizes. Repeatedly, larger remnants with far-from-edge habitats retain more species. This pattern was confirmed, for instance, by Santos *et al.* (2008) when comparing tree assemblages, by Alves-Araújo *et al.* (2008), who listed the plant species richness of various life forms, and by Lima *et al.* (2015), studying herb assemblages. All three studies were carried out in fragmented landscapes within the PEC.

Biodiversity conservation requires adequate biodiversity management and therefore, species knowledge via checklists and inventories is essential. On a broader scale, checklists help define conservation priorities, determine biodiversity hotspots, and identify less sampled taxonomic or functional groups and habitats. They also help to develop strategic zoning and management plans in protected areas at a local scale. Sodhi (2010) pointed out that species inventories have

become increasingly valuable with time. The immense complexity of the Atlantic Forest creates considerable demand for floristic inventories, which are a basis for a wide array of ecological research and for allowing biodiversity conservation planning and decision-making.

The Dois Irmãos State Park is one of the few large fragments in the PEC and one of the most critical urban protected areas in the Atlantic Forest biome, as revised by Marques *et al.* (2021) and defined by law (BRASIL 2006). Therefore, its importance comes from being large, maintaining high biodiversity, and providing a wide range of ecosystem services in the heart of a Metropolitan Region inhabited by around 4 million people (IBGE 2020). By definition, a protected urban area is situated in or at the edge of larger population centres and meets the definition of a protected area. Such spaces are distinctive because they receive many visitors, are threatened by urban development and are disproportionately affected by harmful human practices such as vandalism, pollution, and species invasion (Trzyna 2014). Despite threats, endemic and threatened species thrive, water sources are maintained in terms of quality and quantity, climate regulation is guaranteed, and recreation and environmental educational activities are provided in the PEDI.

The PEDI biodiversity has been studied for decades, mostly through research initiatives restricted to small sites rather than combined efforts into a broader program. The first initiatives to prepare lists of plants for the Park began in the 1980s, firstly for select botanical families and later as a result of a floristic and phytosociological survey of 1.2 hectares (Guedes 1998). This pioneer study was published as a book chapter and included 170 species of Angiosperms, with a focus on tree species. In the same book (Machado *et al.* 1998), other chapters presented lists of 49 avascular species (Pôrto & Oliveira 1998) and 43 species of ferns and lycophytes (Barros 1998). Despite this first effort, there was a lack of a biodiversity compilation that could adequately subsidise the conservation and management of the PEDI. A relevant initiative was the establishment of a research site for the Biodiversity Research Program (PPBio) in the area and its inclusion in a network of research sites across the biome under the Atlantic Forest PPBio Network (PPBio-MA) (Rosa *et al.* 2021). The program's main target is the long-term monitoring and evaluation of changes in the composition and abundance of biodiversity and

the main abiotic factors that affect biodiversity and ecosystem services.

As a follow-up of the PPBio implementation in the PEDI, the Program "Irmãos do Parque" was created as a research initiative in partnership with the park managers to update and improve its Management Plan, providing high-quality biodiversity data and monitoring. As an outcome of both initiatives, this research aimed to prepare the first plant diversity checklist of the Dois Irmãos State Park by elaborating an updated floristic list as an essential step towards the proposition and execution of efficient conservation actions in this prominent remnant of the Atlantic Forest.

Material and Methods

Study area

The Dois Irmãos State Park (Parque Estadual de Dois Irmãos - PEDI) is a remnant of Atlantic Forest, classified as a Lowland Dense Ombrophilous Forest by the IBGE (2012). It is a protected area (IUCN Category II) (SEMAS 2022) located within the urban area of Recife, capital of the state of Pernambuco, Brazil (07°57'22,29"–08°00'56.4"S, 34°56'0.679"–34°58'13.63"W) (Fig. 1), offering a haven of biodiversity in the midst of urban development.

The climate in the region is classified as As' (hot and humid), according to the Köppen-Geiger classification, with average monthly temperatures of above 23 °C and annual average rainfall volumes of 2,263.4 mm, with a rainy season in the autumn-winter period (Data from the Brazilian National Institute of Meteorology repository, period 1981–2010, <portal.inmet.gov.br/normais>). Predominant soil types are ferralsols, acrisols, and arenosols, according to the soil survey of the Northeastern states (Embrapa Solos UEP Recife, <<http://solosne.cnps.embrapa.br>>). The PEDI is located within the watersheds of the Rivers Capibaribe and Beberibe and significantly contributes to the water conservation and supply in the region (SEMAS 2022).

The PEDI forest has a rich history of conservation efforts, dating back to 1885. Its conservation was primarily driven by the need for water catchment from reservoirs in the forest to the City of Recife (SEMAS 2014, 2022). The State Government recognized its ecological value in 1987, categorising it as an Ecological Reserve (Pernambuco 1987). In 1998, it was further elevated to the status of a State Park, covering

387.4 hectares, including four artificial reservoirs (Magalhães *et al.* 2019) and 14 hectares of administration, recreation and a zoological garden (Pernambuco 1998; Rodrigues *et al.* 2022).

In 2014, the PEDI's area increased by 200%, with the addition of 773.02 ha of an adjacent farm covered by a young secondary forest (Pernambuco 2014). Currently, the Park covers 1,157.44 ha, comprising two fragments and a mosaic of three successional stages. The chronosequence in the area is described by Cunha *et al.* (2021) as follows: Mature Forest (MF), which has reached this condition for at least 60 years; Old Secondary Forest (OSF), with ages between 38 and 50 years; and Young Secondary Forest (YSF), younger than 38 years. Despite their importance for biological conservation, provision of ecosystem services and human well-being, both fragments experience severe anthropic disturbances due to their urban neighbourhood and high poverty levels. The PEDI overlaps two protected areas managed by the City of Recife: Area of Relevant Ecological Interest (ARIE) Dois Irmãos and ARIE Beberibe (Recife 2021a, b).

Floristic inventory

The floristic inventory included fieldwork, herbaria, and a literature search. Fieldwork was carried out from 2013 to 2020. Campaigns were performed on a monthly basis in 2014–2015 and 2017–2018 and sporadically in other years, as part of various research projects under the Biodiversity Research Program (PPBio). In 2013, a module of RAPELD (an acronym for Rapid Assessment Surveys - RAP and Long-Term Ecological Research - PELD) (Magnusson *et al.* 2005) was set up in the area. It consists of two 5-km trails, 1 km apart, along which ten plots (250 m × 40 m each) were systematically established following the isolines, totalling a sample area of approximately 10 ha. Research protocols (following Castilho *et al.* 2014) included inventory and monitoring of trees with a diameter at breast height (DBH) ≥ 5 cm and understory plants (DBH < 5 cm) at the three forest successional stages. All collected material was analysed in a stereoscopic microscope for morphological and reproductive characters for botanical identification. Identification keys

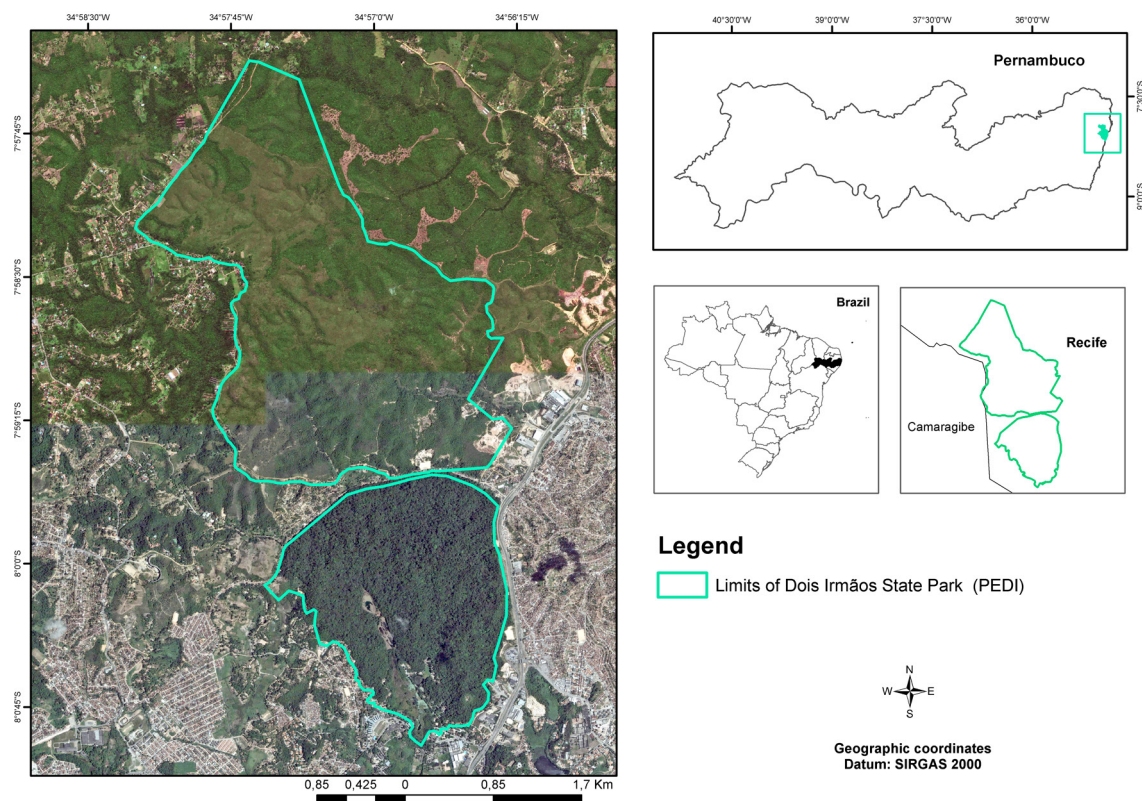


Figure 1 – Location of the Dois Irmãos State Park (PEDI) in Recife, Pernambuco, Brazil. The Southern fragment comprises a mature (old-growth) forest; the Northern fragment comprises two young successional stages.

were used, and websites, quick coloured guides, and specialists, were consulted when necessary. Comparisons were also made with herbaria vouchers in the state of Pernambuco (IPA, PEUFR, UFP, according to Thiers, continuously updated) and the database of the Project Flora e Funga do Brasil 2023 (continuously updated).

After compiling the list from field inventories, we searched for plants (Angiosperms, Ferns and Lycophytes, Avascular plants) collected in the PEDI at the INCT - Virtual Herbarium of Flora and Fungi (<<http://inct.splink.org.br/>>). Plants were only included if their identification was based on images and confirmed by specialists. We also performed a bibliographic search looking for previously published lists of plants, starting in 1980, when the first known plant lists for the area were prepared (Guedes 1998). The bibliography included books, scientific articles in national and international journals, dissertations and theses at the “Portal de Periódicos Capes/MEC”, a Brazilian tool for free access to indexed journals and scientific literature maintained by the Ministry of Education (MEC). References found are listed in Table S1 (available on supplementary material <<https://doi.org/10.6084/m9.figshare.26997547.v1>>).

We prepared a database with all plants, separated into Angiosperms, Ferns and Lycophytes, and Avascular plants. A collector number was added for every species, with only exceptions for Avascular plants, for which 12 species were cited in a book chapter (Pôrto & Oliveira 1998) but with no voucher numbers. For such cases, we added the bibliographic reference in which the species was included. All scientific names were updated and corrected according to Brazilian Flora (Flora e Funga do Brasil 2023, continuously updated). The list of families followed APG IV (2016) and the Brazilian Plants and Fungi Catalogue (Forzza *et al.* 2010). We classified the habitats of angiosperms, ferns, and lycophytes as terrestrial or aquatic. Among terrestrial angiosperms, possible habits included herbaceous or woody, and life forms included trees, shrubs, epiphytes, climbers, parasites and hemiparasites. All aquatic angiosperms, ferns and lycophytes were herbaceous (Magalhães *et al.* 2019). Avascular plants were organised into three Divisions: Anthocerotophyta (hornworts), Marchantiophyta (liverworts) and Bryophyta (mosses) (Cole *et al.* 2019). The species were classified according to their life forms as foliose, mat, thallose, tuft and weft (Costa & Peralta 2015; Flora e Funga do Brasil 2023, continuously updated)

and according to the substrate types (following Robbins 1952) as (1) corticolous, species that grow on living trunks and branches; (2) epiphyllous, those that grow on leaves, (3) epixylic, which grow on dead or decaying trunks; (4) Terricolous, grow on the ground.

Plants were also classified as native or exotic, according to the information available at Flora e Funga do Brasil 2023 (continuously updated). Exotic taxa were considered as those listed as sub-spontaneous or naturalised on the list (Forzza *et al.* 2010). For the exotic plants, we gathered information from the database for Invasive Exotic Species prepared by Instituto Hórus de Desenvolvimento e Conservação Ambiental (2023). Exotic species cited as invasive in the database were assigned to this category. All classifications regarding habitat, life form, habit, origin and extinction risk status followed the information from the consulted published material, herbaria vouchers, Flora e Funga do Brasil 2023 (continuously updated) and CNCFlora (2023).

Results and Discussion

A total of 992 plant species were recorded in the PEDI, distributed across 515 genera and 140 families (Table S2, available on supplementary material <<https://doi.org/10.6084/m9.figshare.26997547.v1>>). Angiosperm was the most species-rich group (887 spp.), followed by Avascular plants (61 spp.) and Ferns and Lycophytes (44 spp.). We present the groups below in order of species richness.

Angiosperms

Regarding habit and life forms, most Angiosperm species were woody plants (576 species, 65%), of which 370 trees (41.7%), 146 shrubs (16.5%), 54 climbers (6.1%) and six palm trees (0.7%). A total of 311 herbaceous species were recorded (35%), including 200 terrestrial (64.3%), 49 aquatic (15.8%), 31 climbers (9.9%), 22 epiphytes (7.1%), five hemiepiphytes (1.6%), three hemiparasites (1%) and one parasitic herb (0.3%) (Fig. 2). This highlights the need for enhanced sampling efforts for epiphytes and climbers, as these groups are often underrepresented in plant surveys but play a crucial role in the ecosystem.

We documented a significantly higher species richness in the PEDI compared to other surveys in the Atlantic Forest in Northeast Brazil (Rodal & Nascimento 2002; Ferraz & Rodal 2008; Rodal & Sales 2008; Melo *et al.* 2011). This finding underscores the unique biodiversity of the PEDI

and the importance of our research in contributing to the understanding of plant diversity in this region. The percentages of woody and herbaceous species were in line with what is typically observed in floristic lists prepared for the Atlantic Forest in Pernambuco (Rodal *et al.* 2005; Nascimento *et al.* 2012). The number of species found in the PEDI is likely a result of the extensive collection effort and time, as well as the large number of researchers and specialists working in the area over many years, rather than any other biological and physical factors that the area presents. Ribeiro *et al.* (1999) demonstrated that systematic surveys that include different life forms can significantly increase the number of species documented in a studied area.

In terms of substrate, PEDI has a higher proportion of terrestrial species (81%), followed by aquatic plants (5.5%) and epiphytes (3%) (Fig. 3a). According to Zappi *et al.* (2015), when evaluating an updated inventory of Brazilian seed plants, records of higher percentages of terrestrial plants is a typical pattern in the Brazilian forest biomes. However, the authors registered the epiphytic substrate, not aquatic plants, as the second most important in species number. In this case, the particular occurrence of four reservoirs in the PEDI must be considered. Moreover, as this is a highly visited State Park, the high number of aquatic species is also influenced by exotic taxa, which increase the number of aquatic species by 12%.

The most species-rich families were Fabaceae (90 spp. species), Poaceae (54 spp.), Rubiaceae (47 spp.), Myrtaceae (35 spp.), Cyperaceae and Melastomataceae (32 spp. each), Asteraceae and Euphorbiaceae (31 spp. each) (Fig. 3a). The two families of trees with the highest species numbers were Fabaceae (55 spp.) and Myrtaceae (33 spp.) (Fig. 3a).

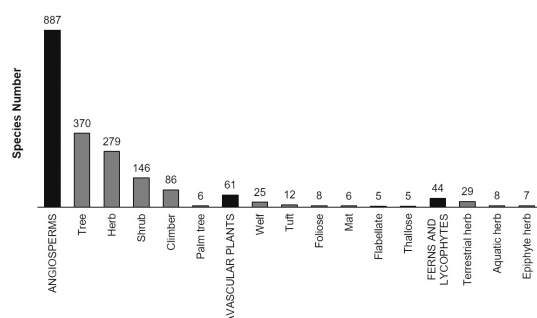


Figure 2 – Species number in different habitats and life-forms, in a protected area of Atlantic Forest, Dois Irmãos State Park (PEDI), in Recife, Brazil.

These results are similar to what is often found in the Atlantic Forest in Pernambuco (Sales *et al.* 1998; Moura & Sampaio 2001; Siqueira *et al.* 2001; Rodal & Nascimento 2002; Alves-Araújo *et al.* 2008; Nascimento *et al.* 2012) and corroborate what Prance *et al.* (1979) and Gentry (1995) quote about the importance of Fabaceae and Myrtaceae in neotropical forests. Fabaceae occupies many forest habitats linked to the family's ecological plasticity (Lima 2000). On the other hand, Myrtaceae species may be abundant due to their crucial function of providing food for wild fauna, with various fruits with fleshy pulp that attract birds, which efficiently disperse their seeds (Mabberley 1997). *Parkia pendula* (Willd.) Benth. ex Walp. and *Albizia pedicellaris* (DC.) L.Rico are examples of Fabaceae and occupy the tallest forest stratum with opulent umbelliform crowns. Below the emergent trees, in the canopy and sub-canopy strata, the Myrtaceae genera *Eugenia* (11 tree species) and *Myrcia* (12 spp.) exhibited the highest species richness (Fig. 3a). *Eugenia umbrosa* O.Berg, *Myrcia racemosa* (O.Berg) Kiaersk., *M. spectabilis* DC. and *Campomanesia dichotoma* (O.Berg) Mattos are endemic tree species to the Atlantic Forest in Northeast Brazil (Amorim & Alves 2011).

Melastomataceae (18 tree species) and Sapotaceae (19 spp.) were also noted among tree species, and we emphasise the importance of the genera *Miconia* (16 spp.) and *Pouteria* (10 spp.) (Fig. 3a) in maintaining frugivore diversity in tropical forests, along with Myrtaceae species (Manhães *et al.* 2003; Stiles & Rosselli 1993; Athie & Dias 2016). Many studies have already documented bird guilds feeding on the fruits and dispersing the seed of *Miconia* species in the Atlantic Forest (Manhães *et al.* 2003; Gridi-Papp *et al.* 2004; Parrini *et al.* 2008; Parrini & Pacheco 2011; Athie & Dias 2016). *Pouteria gardneri* (Mart. & Miq.) Baehni is a Sapotaceae species recorded in the PEDI cited as Vulnerable (VU) in the Brazilian RedList (Martinelli & Moraes 2013), whereas *Chrysophyllum splendens* Spreng. and *Micropholis gardneriana* (A.DC.) Pierre are categorised as Near Threatened (NT). Other tree species in the PEDI are also threatened, among which *Eschweilera alvimii* S.A.Mori (Lecythidaceae), *Ocotea odorifera* (Vell.) Rohwer (Lauraceae), *Paubrasilia echinata* (Lam.) Gagnon, H.C.Lima & G.P.Lewis (Fabaceae), *Sloanea obtusifolia* (Moric.) Schum. (Elaeocarpaceae) and *Trischidium limae* (R.S.Cowan) H.E.Ireland (Fabaceae) are classified as endangered (EN). *Annona pickelii*

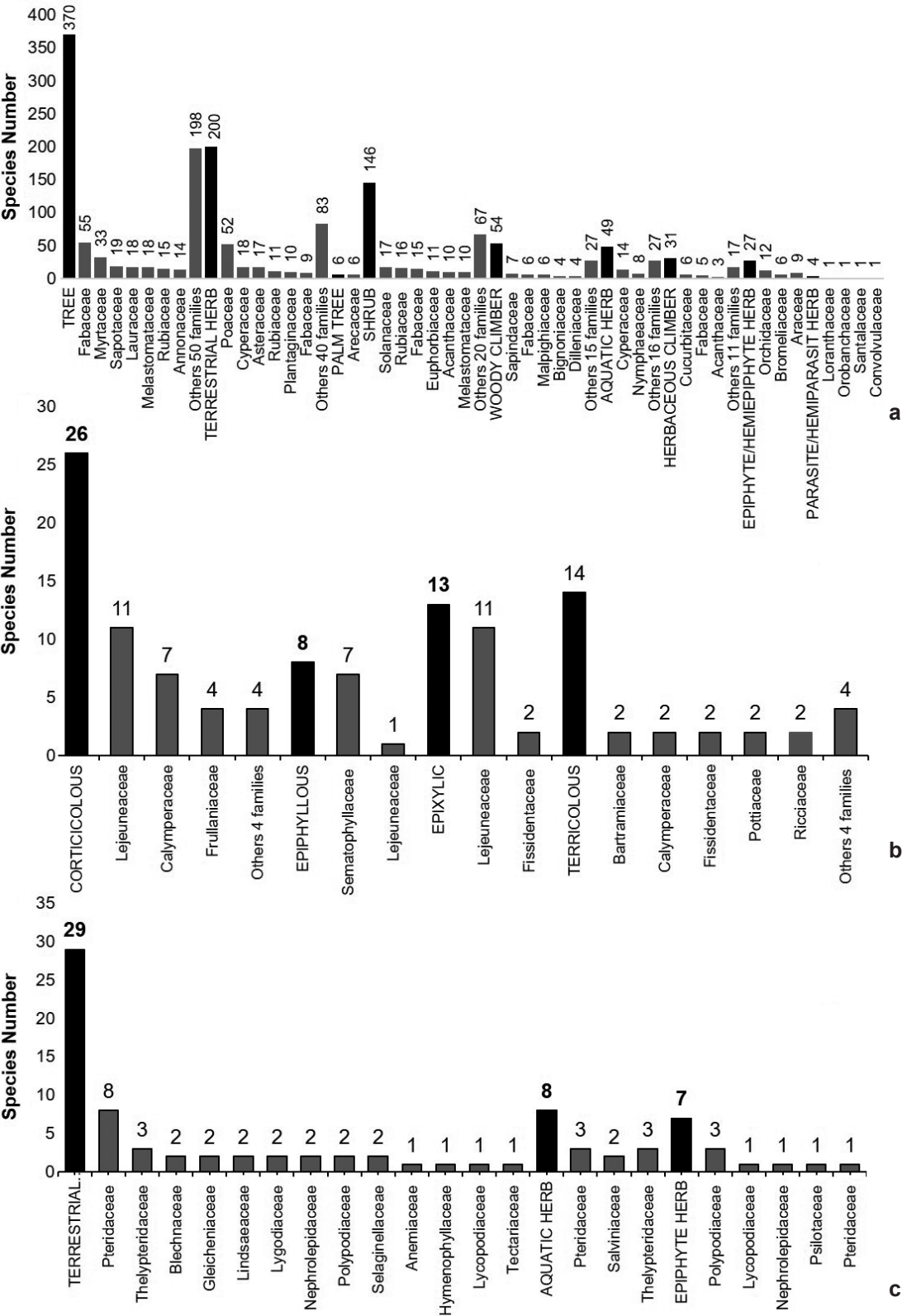


Figure 3 – a-c. Species number in different families of Angiosperms (a), Avascular plants (b), Ferns and Lycophytes (c) and in a protected area of Atlantic Forest, Dois Irmãos State Park (PEDI), in Recife, Brazil.

(Diels) H.Rainer (Annonaceae), *Apuleia leiocarpa* (Vogel) J.F. Macbr. (Fabaceae) and *Cedrela fissilis* Vell. (Meliaceae) are classified as vulnerable (VU) (Martinelli & Moraes 2013).

It is important to highlight three woody species registered with high frequency in the PEDI that are not listed as occurring in the state of Pernambuco in the Brazilian Plants database (Flora e Funga do Brasil 2023, continuously updated): *Himatanthus phagedaenicus* (Mart.) Woodson (Apocynaceae), *Eschweilera alvimii* S.A.Mori (Lecythidaceae) and *Pouteria torta* (Mart.) Radlk (Sapotaceae) (Tab. S2, available on supplementary material <<https://doi.org/10.6084/m9.figshare.26997547.v1>>). The first two have also been recorded in other fragments of the Atlantic Forest in Pernambuco (Amorim *et al.* 2016; Guimarães *et al.* 2009; Melo *et al.* 2011), while *P. torta* was found in the state by Alves-Araújo & Alves (2010). All three are registered for the state in the databases from CRIA (Specieslink).

Amongst the shrubs, the families Rubiaceae (16 spp.), Solanaceae (17 spp.), Fabaceae (15 spp.) and Euphorbiaceae (11 spp.) were the richest (Fig. 3a). Within the herbs, we highlight Poaceae (54 spp.), Cyperaceae (32 spp.), Asteraceae (19 spp.) and Rubiaceae (13 spp.) in terrestrial and aquatic habitats, all with the maximum richness for the habit (Fig. 3a). A high number of Rubiaceae species were in the genus *Palicourea* (9 spp.), composed of shrubs, and *Borreria* (7 spp.), consisting of aquatic and terrestrial herbs (Tab. S2, available on supplementary material <<https://doi.org/10.6084/m9.figshare.26997547.v1>>; Fig. 3a). Alves-Araújo *et al.* (2008) similarly described the importance of these families in the lower strata of Atlantic Forest fragments in Pernambuco. We highlight the presence of *Rudgea umbrosa* Müll.Arg., a shrub species that is also vulnerable (VU) to extinction (Martinelli & Moraes 2013).

Solanaceae is one of the most prominent families with shrubby/ herbaceous habits in secondary forests and anthropic areas in Brazil and South America (Nee 2007). In the PEDI, the genus *Solanum* (12 spp.) is well represented, with species in the understory, such as *Solanum capsicoides* All., a frequent shrub along forest edges and roadsides (Tab. S2, available on supplementary material <<https://doi.org/10.6084/m9.figshare.26997547.v1>>). Another common species in the PEDI, *S. paniculatum* L., is included in the National List of Medicinal Plants (RENISUS 2009). *Solanum* spp. occur in the Atlantic Forest from the sea level up to more than 700 m altitude, forest gaps, “restingas”

edges and interior of dense and open forests, and anthropic environments (Agra *et al.* 2009; Sampaio 2013). Asteraceae, Cyperaceae and Poaceae are also common in disturbed environments, as Lima (2016) described when evaluating the herbaceous assemblage in mature and young forests in Pernambuco. *Elephantopus mollis* Kunth, *Emilia fosbergii* Nicolson, *Eclipta prostrata* (L.) L. (Asteraceae) and *Paspalum millegrana* Schrad. ex Schult. (Poaceae) are examples of species recorded in the PEDI in such anthropic environments (Teles & Bautista 2006; Maciel & Alves 2014). Herbaceous species such as *Kalanchoe crenata* (Andrews) Haw. (Crassulaceae), which is a naturalised exotic, and *Heliconia farinosa* Raddi (Heliconiaceae), native to Southern and Southeastern Brazil, were recorded at the edges of the PEDI forest, which can probably be explained by the incorrect management of the Park’s gardens at the Zone for Anthropic Use (SEMAS 2022).

In contrast, other PEDI species, such as *Ichnanthus leiocarpus* (Spreng.), indicate well-conserved forests. Kunth, *Olyra latifolia* L. (Poaceae), and *Rhynchospora comata* (Link) Roem. & Schult. (Cyperaceae) (Maciel & Alves 2014; Lima 2016). These findings show that the herbaceous stratum is highly diversified and holds some of the most sensitive and threatened species. The herbs’ short life cycles and rapid responses to environmental changes make them very useful for assessing the conservation status of forests (Roberts & Gilliam 2003; Paim *et al.* 2005).

There were 27 species of angiosperm epiphytes and hemiepiphytes on the list, and we draw attention to the families Orchidaceae (12 spp.), Araceae (9 spp.) and Bromeliaceae (6 spp.) (Fig. 3a). According to Kersten (2010), these families are the most representative as Atlantic Forest epiphytes. However, the number of species in the PEDI is much lower than those recorded in the biome within the Northeastern Brazilian region (Siqueira Filho & Fénix 2006; Pontes *et al.* 2010; Pessoa & Alves 2012; Araújo *et al.* 2019). Low numbers may be explained by low sampling effort and difficulty accessing and collecting these plants. Regarding Araceae, Pontes *et al.* (2010) found 18 species in fragments of the Atlantic Forest in Pernambuco, citing the genera *Philodendron* and *Anthurium* as the most representative in species numbers. In the PEDI, species such as *Anthurium gracile* (Rudge) Lindl., *A. pentaphyllum* (Aubl.) G.Don and *A. scandens* (Aubl.) Engl have been found to occur. Croata (1986) states that these

species are epiphytes widely distributed in the Americas. In contrast, *Philodendron blanchetianum* Schott is a hemiepiphyte restricted to the Atlantic Provinces in Brazil, from Pernambuco to the state of Espírito Santo (Pontes & Alves 2011).

Félix & Carvalho (2002) listed approximately 250 Orchidaceae species for the state of Pernambuco, of which 239 species occur in the Atlantic Forest, evidencing the family's high diversity. Focusing their sampling on six fragments in Pernambuco, Pessoa & Alves (2012) recorded 27 species of Orchidaceae. Comparing their list to the PEDI list, only *Dichaea panamensis* Lindl., *Dimerandra emarginata* (G.Mey.) Hoehne, and *Epidendrum rigidum* Jacq. appear in both lists, which shows that a high species richness complementarity is exhibited in this family.

Surveys on epiphytes have often reported bromeliads as one of the main components of the Atlantic Forest (Marques 1997; Assis *et al.* 2004; Amorim *et al.* 2005; Moura *et al.* 2007; Martinelli *et al.* 2008; Fontoura & Santos 2010; Cavalcante *et al.* 2017). According to Martinelli *et al.* (2008), around 40% of Bromeliaceae species are at risk of extinction in the Atlantic Forest. Siqueira Filho (2003) recorded 87 species and 41 endemics in the states of Pernambuco and Alagoas, cited as this family's Endemism Center. *Canistrum aurantiacum* E.Morren and *Hohenbergia ridleyi* (Baker) Mez are examples of endemic species recorded in the PEDI.

Epiphyte species can positively affect ecological processes and, thus, are fundamental for maintaining ecosystem functioning. The group provides a wide variety of microhabitats and micro-climates and contributes to a richer and more diverse fauna (Duarte & Gandolfi 2013; Araújo *et al.* 2019). Moreover, they are potential bioindicators of climate change, pollution and ecosystem disturbances (Kersten 2010). Thus, it is necessary to enhance the sampling efforts of epiphytes in the PEDI, which is very likely underestimated. Such an initiative will likely increase the group's biodiversity, allow for the monitoring of epiphyte populations, and support the evaluation of the forest conservation status.

Climbers compose 9.8% of the angiosperm flora in the PEDI, with 85 species, 54 woody (64%) and 31 herbaceous (36%), in 30 families. Sapindaceae (7 spp.), Fabaceae and Malpighiaceae (6 spp. each) exhibited the highest number of species with the woody habit, whereas Cucurbitaceae (6 spp.) and Fabaceae (5 spp.) were the richest

among herbaceous climbers (Fig. 3a). To illustrate the benefits of the group, we mention the woody *Macropsychanthus grandiflorus* (Mart. ex Benth.) L.P.Queiroz & Snak (Fabaceae), with a high ornamental potential for its purple-blue big flowers and the herbaceous *Cayaponia tayuya* (Vell.) Cogn. (Cucurbitaceae), with medicinal potential, used for centuries by traditional communities in the Amazon for treating snake bites and rheumatism (Ruppelt *et al.* 1991).

According to Gentry (1991), woody climbers grow easily in interior forest habitats far from anthropic influence, while herbaceous climbers often occur on forest edges or highly anthropic environments. Our findings of a more significant number of woody climbing species in the PEDI may indicate a good conservation status of the forest. However, more studies are needed to validate this supposition. Additionally, herbaceous climbers can help to understand and monitor the effects of global warming, acting as valuable indicator species (DeWalt *et al.* 2010; Schnitzer *et al.* 2012; Gerolamo *et al.* 2018). Over the last few years, there has been a growing focus on the study of climbers, especially in the Atlantic Forest (Tibiriçá *et al.* 2006; Barros *et al.* 2009; Santos *et al.* 2009; Udulutsch *et al.* 2010; Villagra & Neto 2011; Carneiro & Vieira 2012; Vargas *et al.* 2013; Scudeler *et al.* 2019). Nevertheless, one of the main difficulties in studying the floristics of this group is the access to individuals and their fertile parts, which are often only found in the tree canopy.

Villagra & Neto (2011) and Scudeler *et al.* (2019) also registered Fabaceae as the most eminent family of climbers in Atlantic Forest fragments in São Paulo. These floristic elements are essential for forest ecosystem richness, structure, and functioning (Gentry 1991; Engel *et al.* 1998). In Pernambuco, however, there are few studies on forest climbers (Araújo & Alves 2010; García-Gonçalves 2011; Oliveira *et al.* 2012). Araújo & Alves (2010) documented 93 climber species in forest fragments, including Fabaceae, Cucurbitaceae, Convolvulaceae and Passifloraceae. These authors registered nine Passifloraceae species, including *Passiflora mansoi* (Mart.) Mast., *P. misera* Kunth and *P. ovalis* Vell. ex M.Roem., the only three climbers representative of the family found in the PEDI thus far.

Avascular plants

A total of 61 avascular plant species were registered, most of which (31 species, five families)

fall into the Division Marchantiophyta (liverworts): Calypogeciaceae, Frullaniaceae, Lejeuneaceae, Plagiochilaceae, Ricciaceae). Eight families and 28 species were recorded in the Division Bryophyta (mosses): Bartramiaceae, Bryaceae, Calymperaceae, Fissidentaceae, Helicophyllaceae, Hypnaceae, Pottiaceae and Sematophyllaceae. Anthocerotophyta (hornworts) was represented by two species and two families (Anthocerotaceae and Notothyladaceae). The most important families in the group of avascular plants were Lejeuneaceae (23 spp.), Calymperaceae (9 spp.) and Sematophyllaceae (7 spp.) (Fig. 3b). According to Silva & Porto (2014), 403 species of bryophytes are known in the Northeastern Atlantic Forest, with the predominance of families such as Calymperaceae and Fissidentaceae. The richest families in the PEDI (Lejeuneaceae, Calymperaceae and Sematophyllaceae) are among the ten most prominent families of mosses and liverworts in Brazil (Costa & Peralta 2015), with pantropical distribution, and are likely to be the most common in the tropics (Carvalho-Silva *et al.* 2017).

Among avascular species, the weft life form was predominant (25 spp.), represented by the family Lejeuneaceae (23 spp.) as the most abundant, followed by the tuft (12 spp.), with Calymperaceae (9 spp.) as the richest for this category (Fig. 2; Tab. S2, available on supplementary material <<https://doi.org/10.6084/m9.figshare.26997547.v1>>). In the Brazilian bryoflora and the Atlantic Forest biome, foliose is the most abundant life form, followed by tuft, mat and weft in the fourth position (Costa & Peralta 2015). However, the predominant weft or trama type is common in lowland secondary and degraded rainforests (Germano & Pôrto 2006). This life form grows into shady and mesophytic habitats (Glime 2017), similar to what is found in the studied forest.

Among the colonised substrates, corticolous plants were the most dominant, with 22 species (35%), followed by epixilic (13 spp., 21%), terrestrial (22%) and epiphyllous (10%). The Atlantic Forest is considered one of the main centres of endemism for avascular plants due to the particular environmental conditions that favour their establishment (Costa & Peralta 2015). Corticolous species were well represented mainly by the Lejeuneaceae and Calymperaceae families, which, according to Gradstein *et al.* (2001), stand out in richness and diversity in tropical forests.

Many corticolous species are common in forest environments as they preferentially colonise the bark or trunks of trees and shrubs (Gradstein *et al.* 2001). Epixilic species can be good indicators of canopy quality, as they are considered shadow species that are particularly vulnerable to disturbances in the ecosystem (Zarnowiec *et al.* 2021). They are the first bryophytes to disappear and reduce their richness and abundance due to habitat disturbance when the forest canopy is open (Gradstein 1997; Gradstein *et al.* 2001; Gentil & Menezes 2011; Zarnowiec *et al.* 2021).

Ferns and Lycophytes

There were 44 species in 16 families of Ferns and Lycophytes on the list, of which the most important were Pteridaceae (12 spp.), with emphasis on the genus *Adiantum* (6 spp.), followed by Thelypteridaceae (6 spp.) and Polypodiaceae (5 spp.), with terrestrial, herbaceous, and epiphytic habitats (Fig. 3c). The number is similar to that of Barros (1998), who previously carried out a survey in the same forest. In other floristic surveys in rainforests in the same region, registered lower numbers than those found in the PEDI. Barros *et al.* (1996) and Farias *et al.* (1992) recorded 16 species each, while Ambrósio & Barros (1997) found 25 species, Fonseca-Dias & Barros (2001), 24, Santiago & Barros (2003), 21. However, when surveying a more extensive area covering 12 forest fragments, Barros *et al.* (2002) registered 131 species in 19 families. Therefore, it is clear that the floras of Ferns and Lycophytes and their complementarity between areas, are high in the region.

The PEDI region is characterised by the dominance of two families, Pteridaceae and Polypodiaceae, which are not only frequently highlighted in floristic surveys in Brazil (Prado *et al.* 2015), but also hold significant representativity in the Neotropical region (Tryon & Tryon 1982). The presence of Hymenophyllaceae, a rarity in the Northeast Region (Barros *et al.* 2002), adds to the unique flora of the PEDI. The most common genus, *Adiantum*, is a familiar sight in the Northeast, particularly in less-conserved environments with visible anthropic disturbances, such as forest edges (Xavier & Barros 2005).

Some species, like *Psilotum nudum* (L.) P.Beauv. (Barros & Santiago 2007; Flora e Funga do Brasil 2023, continuously updated) and *Ceratopteris thalictroides* (L.) and *Ceratopteris thalictroides* (L.) Brongn., stand out for their

potential as ornamental plants, the latter of which is a rooted mud plant with few records in herbaria (Santiago *et al.* 2014), adding to the unique characteristics of the PEDI flora.

The flora of Ferns and Lycophytes in the PEDI is not confined to a single habitat, but spans both open and sunny areas and forest interiors (Fig. 2). This information is based on direct observation and data from herbaria vouchers. The majority of the species (29, 66%) are terrestrial, a trend that is consistent with other surveys of Ferns and Lycophytes (Barros *et al.* 2002). The remaining species include 8 aquatic (18%) and 7 epiphytic (16%) varieties (Fig. 2). The prevalence of epiphytic ferns in high humidity and well-conserved sites is a testament to their sensitivity to environmental disturbances, particularly anthropogenic pressure (Sota 1971).

The PEDI region, with its diverse Fern and Lycophyte flora, is not only a research site of interest but also a crucial habitat for these species. Habitat loss and fragmentation pose direct threats to Ferns and Lycophytes, considering that most species inhabit moist and shadowed microhabitats in the forest interior (Barros *et al.* 2006). The availability of proper conditions in natural ecosystems, such as springs or water bodies, is crucial for the colonisation by Fern species, as affirmed by Barros *et al.* (2006). The ability of species to thrive and establish populations, even in disturbed sites if primary conditions are met, underscores the importance of maintaining these conditions in the PEDI region.

Exotic species

Among the recorded plants in the PEDI, 40 (4%) exotic species were found, of which 20 are considered invasive (Instituto Hórus de Desenvolvimento e Conservação Ambiental 2023; Table S2, available on supplementary material <<https://doi.org/10.6084/m9.figshare.26997547.v1>>). The number of exotic species is likely to increase with floristic surveys focused on this group of plants. We strongly advocate for new surveys to fill this gap since exotic and invasive species are observed occupying the edges and gardens of the protected area. Regarding the exotic species' habits, 17 (42.5%) are herbs (terrestrial and aquatic), nine (22.5%) are trees, and seven (17.5%) are shrubs (Table S2, available on supplementary material <<https://doi.org/10.6084/m9.figshare.26997547.v1>>). Many species have ornamental potential, such as *Ficus benjamina* L. (Moraceae) and

Nymphaea lotus L. (Nymphaeaceae), both of Asian origin, where the former has been widely used in the past for afforestation in the city of Recife and the latter for ornamenting lakes in gardens.

The invasive trees *Mangifera indica* L. (Anacardiaceae) and *Artocarpus heterophyllus* Lam. (Moraceae), both of Asian origin, are alarmingly prevalent in the PEDI, as well as in numerous other Atlantic Forest fragments in Northeast and Southeast Brazil (Abreu & Rodrigues 2010; Fabricante *et al.* 2012; IBGE 2015; Freitas *et al.* 2017). The hot and humid climate, along with the more distinct dry periods, create favourable conditions for these two species to colonise the region, where they are classified as being at medium risk of invasion (Leão *et al.* 2011). The high fruit productivity and ease of germination of *Artocarpus heterophyllus* further facilitate its spread in forest fragments (Fabricante *et al.* 2012), leading to significant changes in the composition, diversity, and structure of native species assemblages (Abreu & Rodrigues 2010; Geiseler 2014).

The presence of these invasive exotic species underscores the urgent need for a permanent monitoring program in the PEDI, which should include a comprehensive survey of invasive species distribution and a plan for invasion control to protect the rich plant diversity of the Atlantic Forest remnant.

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Data availability statement

In accordance with Open Science communication practices, the authors inform that all data are available within the manuscript.

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