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Ferns and Lycophytes as new challenges

The exotic species *Pteris ensiformis* (Pteridaceae) in South America: an aproach to naturalization process

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Abstract

Pteris has numerous representatives of Asian and Oceanic origin naturalized in America, some of them recognized as invasive weeds. *Pteris ensiformis* was introduced in America in the middle of the 19th century and subsequently naturalized in USA and Central America, but the records of its distribution in South America are isolated and the establishment or naturalization of the populations is unclear. As part of a broader study whose objective is to review the diversity of ferns and lycophytes in the Paranaense forest *P. ensiformis* was found for the first time in Argentina. In addition to describing, illustrating, and distinguishing the species from other species of the genus in the country, we review the distribution of *P. ensiformis* in South America comparing herbarium collections and iNaturalist observations, a citizen science platform. Additionally, a status for the species is proposed or suggested in each country where it is registered according to its stage of the naturalization process.

Key words: Argentina, collections, ferns, iNaturalist, naturalization.

Resumen

Pteris posee numerosos representantes de origen asiático y oceánico naturalizados en América y algunos de ellos reconocidos como malezas invasoras. *Pteris ensiformis* se introdujo en América a mediados del siglo XIX y posteriormente se naturalizó en USA y Centroamérica, pero los registros de su distribución en Sudamérica son aislados y el establecimiento o naturalización de las poblaciones no está claro. Como parte de un estudio más amplio cuyo objetivo es revisar la diversidad de helechos y licofitas de la selva paranaense, *P. ensiformis* se registra por primera vez en Argentina. Además de describir, ilustrar, y distinguir la especie de otras especies del género en el país, se presenta una revisión completa de la distribución de *P. ensiformis* para Sudamérica, comparando colecciones de herbario y datos obtenidos de iNaturalist, una plataforma de ciencia ciudadana. Adicionalmente, se propone un estatus para la especie en cada país donde se encuentra registrada de acuerdo a su etapa en el proceso de naturalización.

Palabras clave: Argentina, colecciones, helechos, iNaturalist, naturalización.

See supplementary material - complete list of records studied in this manuscript and the status assigned - at <https://figshare.com/account/home#/projects/162196>

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Introduction

Pteris ensiformis Burm. f. ("Silver lace fern" or "slender brake") is a species native to Asia and Oceania (Holttum 1966; Zhang *et al.* 2013), distinguished from other species of the genus by sword-shaped fertile segments ("ensiform") with acute and serrated apices, and once-forked veins. Although in the past the species was included within the *Pteris cretica* L. complex due to its dimorphic fronds and laminae with a continuous and elongated terminal segment (Tryon & Tryon 1982; Martinez 2011), recent phylogenies from chloroplast and nuclear markers place the species within a monophyletic section "ensiformis" (Zhang *et al*. 2015; Zhang & Zhang 2018). This morphologically diverse clade includes an estimated 10 species.

Because of its ornamental use, *Pteris ensiformis* is thought to have been introduced in America in the middle of the 19th century and subsequently naturalized in USA (Florida), Mexico, Cuba, Jamaica, and Puerto Rico (Lellinger 1985; Proctor 1989; Martinez 2011; Palacios-Rios *et al.* 2016; Jones *et al.* 2019). In recent decades its presence in cultivation or as an escape has been recorded in some countries of South America such as Chile (Macaya 2008) and Ecuador (Guézou *et al*. 2010). More recently, stable and healthy populations have been found in distant states of Brazil (Paraná, Espírito Santo, and Minas Gerais), and many authors have pointed out its ability to establish without human intervention (Funez *et al.* 2017; Schwartsburd *et al.* 2017; Matos *et al.* 2020; Miranda 2020). Despite this, the species has not yet been registered as naturalized in Brazil (Prado *et al.* 2015; Prado & Hirai 2023).

As in many countries in South America, knowledge about exotic species of ferns and lycophytes in Argentina is scarce, especially when compared to angiosperms and gymnosperms. This is mainly due to the fact that exotic fern species are rarely collected, they are poorly represented in herbarium collections, and are excluded in local and regional floristic works in the country (Ponce *et al.* 2008; Ponce & Arana 2016). This bias in collections becomes evident when new records of both flora and fauna are found by using alternative data sources such as citizen science tools (Khapugin *et al*. 2020; Ceccolini 2021; Mo & Mo 2022). Moreover, the consequences of the introduction of fern species for natural environments and native flora remain little-studied.

So far 11 exotic species of ferns have been recorded for Argentina (Yañez *et al*. 2020), in contrast with the 458 species of seed-plants currently reported (InBiAr 2023). The cosmopolitan fern genus *Pteris* L. (subfamily Pteridoideae, Pteridaceae; PPG I 2016) contributes disproportionately to the country's exotic fern flora. Of the 14 species of *Pteris* that grow in Argentina, four are native to Europe, Southeast Asia, and Australia: *Pteris cretica* L., *Pteris multifida* Poir, *Pteris tremula* Poir., and *Pteris vittata* L., and most of them are reported as invasive weeds in natural or ruderal environments of America (Capurro 1969; De La Sota 1977; Prado & Windisch 2000; Martinez 2011; Mazumdar & Arana 2016). In many cases the origin of the introduction is their use as ornamentals and, particularly in *Pteris vittata*, urbanized areas are one of the main habitats of the species. Several authors have pointed out the capacity of some cosmopolitan species of *Pteris* to colonize new and distant habitats, and this is due to adaptive advantages such as apogamic reproduction and self-fertilization of gametophytes (Walker 1962; Watano 1988; Kawakami *et al.* 1995; Martínez 2010).

As the *Pteris* collections in Argentina increase, new finds are recorded. Recently, five naturalized populations of *Pteris tremula* have been detected growing in the coast of Río de La Plata (Buenos Aires), in diverse environments like flooded scrublands, marginal forest, and, mainly, disturbed habitats (Arana *et al.* 2020a). Additionally, the known distribution of *Pteris cretica* has expanded towards the center of the country, and var. *laeta* Ching has been reported for the first time in natural environments of Comechingones biogeographic province growing in the banks of watercourses like streams with dark, silty soil with abundant organic matter (Arana *et al*. 2017, 2020b).

As part of a broader study, whose objective is to study the diversity of ferns and lycophytes in the Paranaense forest with emphasis on the protected areas of northeastern Argentina (Marquez *et al*. 2016, 2020; Kelly *et al*. 2019; Yañez *et al*. 2022), *Pteris ensiformis* is recorded for the first time in the country, growing in the province of Misiones. In the present work the populations found are documented, the species is illustrated, and a key is provided to distinguish it from the *Pteris* species from Argentina. Additionally, data from both herbarium specimens and iNaturalist observations

are compared to present an overview of the distribution of *P. ensiformis* in South America. Finally, a status for the species is proposed in each country where it is registered according to its stage of the naturalization process.

Material and Methods

Studied material of new records from Argentina

Specimens of *Pteris ensiformis* in Argentina were collected on field trips to Misiones province in 2020, 2021, and 2023. They were processed under standard techniques, and vouchers were deposited in BA (Museo Argentino de Ciencias Naturales "Bernardino Rivadavia"), LP (Museo de La Plata) and SLP (Instituto Misionero de Biodiversidad), and live specimens were conserved in El Puma Ecological Park (Misiones, Argentina). Additionally, specimens deposited in CTES (Instituto de Botánica del Nordeste) were studied.

For identifications we used floristic literature from the native area of the species (Holttum 1966; Kramer & McCarthy 1998; Zhang *et al.* 2013). We consulted Argentine Vascular Flora (Martinez & Prado 2016) and local floras (Marquez *et al.* 2006; Tressens *et al.* 2008; Kelly *et al.* 2019) to build the key for *Pteris* species. The classification proposed in PPG I (2016) was followed.

In order to infer the reproductive mode of the specimens found, we counted the number of spores per sporangium in at least five sporangia with normal spores. Specimens with 64 spores per sporangium were assumed to be sexually reproducing, and specimens with 32 spores per sporangium were considered to be apogamous (Manton 1950).

Review of distribution and naturalization status of the species in South America

To the review of the species distribution in South America online we consulted herbarium specimen databases such as GBIF (2023), SpeciesLink (2022), REFLORA (2022), PteridoPortal (2023), and collections and databases from the following herbaria: BA, CTES, LP and SI (Argentina), LPB (Bolivia), FURB, JPB, MBM, PACA, RB, SLUI, SPF, UPCB, VIC (Brazil), COL, HUA, CDMB, CUCV (Colombia), FCQ, PY, SCP (Paraguay), HUT, HOXA (Perú), and GUYN and VEN (Venezuela).

We also consulted regional floras to the review of the species distribution in South America (Smith 1985; Tryon & Stolze 1989; Rodriguez 1995; Smith & Lellinger 1995; Boggan *et al.* 1997; Arbelaez & Jørgensen 1999; Baksh-Comeau 2000; Jørgensen *et al.* 2014; Bernal *et al.* 2016; Kessler *et al.* 2017; Martinez & Prado 2016; Zuloaga *et al.* 2019; Paraguay Checklist 2016), and local floras (Funez *et al.* 2017; Schwartsburd *et al.* 2017; Matos *et al.* 2020; Miranda 2020). Additionally, compilations of exotic species available for some countries in the region such as Argentina (Marzocca 1986; Fernandez *et al.* 2016; Yañez *et al.* 2020), Chile (Macaya 2008), and Venezuela (Ojasti 2001) were reviewed.

Finally, we reviewed observations of *P. ensiformis* on the iNaturalist platform (iNaturalist 2022) in order to evaluate the hypothesis about the lack of herbarium collections of the species and detect populations not surveyed up to now. These observations were reviewed individually to confirm identification and to distinguish the records belonging to cultivated individuals from those growing out of cultivation. The latter were the ones used for the analysis of the distribution.

The state in the naturalization process of the species was analyzed considering only the populations that are supported by vouchers deposited in herbarium collections. Habitat, size of population, maturation, and fertility status of individuals were extracted from the label data, as well as from the consulted bibliography to review the distribution.

We follow the terminology proposed by Richardson *et al*. (2000), Pyšek *et al*. (2004), and Falk-Petersen *et al*. (2006). In Table 1 we don't transcribe the literal definitions of the authors, but rather a combination of them that does not change their meaning. Additionally, we follow the stages of an alien species in an invaded region proposed by Blackburn *et al*. (2011, fig. 1, p. 335). Because we consider it premature to talk about "invasion" to describe the *P. ensiformis* presence in South America, we will refer to the process described by this last author as "naturalization process". In this sense, we classify each particular record as: Not determined - there is not enough information to determine its status; Cultivated - the specimen grows under human control; Casual - the specimen is a juvenile growing outside of cultivation (*e.g*., in cracks on a natural rock or urban walls) but there is no evidence that they are part of a self-sustaining population; Naturalized - there are

Table 1 – Terminology used in this article referring to the status of an exotic species in the invaded area. *Adventive (De Candolle's 1855) is pointed out by Richardson *et al.* (2000) and Pyšek *et al.* (2004) as a synonym of casual. **While for Richardson *et al.* (2000) one way to identify that a population has reached its state of naturalization is that they tend to recruit descendants freely, generally near adult plants, Pyšek *et al.* (2004) propose a period of 10 consecutive years of self-replacement of populations to support the naturalization status. In this work we follow Richardson's naturalization criteria but we make observations of the temporary permanence of the species in a given area.

Definition	Status	References
Native	Plant taxa that have originated in a given area without human involvement or that have arrived there without intentional or unintentional intervention of humans from an area in which they are native.	Pyšek *et al.* (2004); Falk-Petersen *et al.* (2006).
Non-native / alien / exotic / nonindigenous plants	Plant taxa in a given area, outside its natural past or present range, whose presence there is due to intentional or unintentional human involvement, or which have arrived there without the help of people from an area in which they are alien (organisms whose dispersal is caused by human action)	Richardson *et al.* (2000); Pyšek *et al.* (2004); Falk-Petersen *et al.* (2006).
Cultivated	Plant taxa growing under human control, whose sustainability depends on it.	Pyšek *et al.* (2004)
Casual / adventive*	Alien plants that may flourish and even reproduce occasionally outside cultivation in an area, but that eventually die out because they do not form self-sustaining populations, and rely on repeated introductions for their persistence.	Richardson *et al.* (2000); Pyšek *et al.* (2004); Falk-Petersen *et al.* (2006).
Naturalized**	Alien plants that reproduce consistently and have obtained a self-sustaining population over many life cycles without direct intervention by humans (or in spite of human intervention). They do not necessarily invade natural, seminatural or human-made ecosystems.	Richardson *et al.* (2000); Pyšek *et al.* (2004); Falk-Petersen *et al.* (2006).

records of the presence of free descendants, near adult plants; Out of cultivation - the specimen grows out of human control but there is not enough information to determine if it is a casual event or a naturalization (see Supplementary Information 1 in Figshare to complete list of records and its classification: <https://figshare.com/account/home#/projects/162196>). It is important to note that while for Richardson *et al.* (2000) one way to identify that a population has reached its state of naturalization is that they tend to recruit descendants freely, generally near adult plants, Pyšek *et al.* (2004) propose a period of 10 consecutive years of self-replacement of populations to support the naturalization status. In this work we follow Richardson's naturalization criteria but we make observations of the temporary permanence of the species in a given area. Records classified as "Casual" were considered to belong to the "Establishment" stage, in which individuals surviving in the wild (*i.e.*, out of cultivation), don't reproduce or they do reproduce but the population is not self-sustaining (Categories C1 and C2 of Blackburn *et al*. 2011). Records classified as "Naturalized" were considered to belong to the "Spread" stage in which individuals survive in the wild, they reproduce, and the population is self-sustaining (Category C3 of Blackburn *et al.* 2011). Later stages described by the author were not taken into account due to the impossibility of identifying the localities where the species was originally introduced (Categories D1, D2, and E). Subsequently, we assigned a general status in the naturalization process of the species for each country considering the status of the particular record that corresponds to a later stage (Tab. 2).

Maps were prepared showing the records distribution according to: a- the varieties for *P. ensiformis*; b - the databases consulted (Herbaria specimen vs iNaturalist); c - the status assigned in this article; d - the year of collection. While for maps a and b both the records of individuals out of cultivation from iNaturalist and herbariums were used, for c and d only the records from herbaria

Table 2 – Status and stages in the naturalization process of South America populations according to information of herbarium collections. Between parentheses = number of total records from herbarium collections. *We assign a general status in the invasion process of the species for each country considering the status of the particular record that corresponds to a later stage according to the scheme proposed by Blackburn *et al.* (2011).

Status / Country and number of records	Not determined	Cultivated	Casual	Naturalized	Out of cultivation	Status defined in this article*	Stage sensu Blackburn *et al.* (2011)
Brazil (31)	3	7	1	3	17	Naturalized	Spread (C3)
Colombia (4)	4	0	0	0	0	Not determined	Not determined
French Guiana (2)	1	1	0	0	0	Cultivated	Introduction
Ecuador (2)	0	2	0	0	0	Cultivated	Introduction
Argentina (4)	0	0	3	0	1	Casual	Establishment (C1 and C2)

were considered, both of cultivated and non-cultivation individuals.

The maps were made using QGIS 3.28.3 and the base layers were downloaded from <https://geodata.lib.utexas.edu/> (Fig. 3).

Results and Discussion

Pteris ensiformis in Argentina

The new records were found in distant places from each other (ca. 200 km away) in the western part of Misiones province. The record belonging to Puerto Iguazu locality (Dept. Iguazú) (*Márquez et al. 741*, SLP) was found growing spontaneously in undergrowth, within the Iryapu Municipal Reserve, on the edge of the reserve's main road. The record that belongs to San Ignacio locality (Dept. San Ignacio) (*Gutiérrez et al. 1638*, BA) was found growing on the side of a secondary road, next to a fence. Finally, the population recorded in Puerto Rico (Dept. Libertador General San Martín) (*Castía 315*, SLP) comprises 4 plants growing inside a *Pinus elliottii* Engelm. plantation, surrounded by marginal secondary forest and near a stream.

Although in all cases the specimens collected were fertile, only a few mature individuals were observed in the population, and it is not possible to ensure whether they were part of a population capable of self-sustaining. However, the discovery of a fourth record collected in 2003 in Puerto Bossetti locality (Dept. Iguazu) suggests the presence of the species in the study area for more than 10 years, which would indicate that it is in the process of naturalization (Pyšek *et al.* 2004). Subsequent trips to collection localities are necessary to ensure the effective naturalization of the species in the country.

Additionally, a recent iNaturalist observation locates the species growing out of cultivation, near a trail in Foester Provincial Park.

Key to *Pteris* species from Argentina

1. Venation simple to furcate.
   2. Laminae proximally not ternate.
      3. Petiole and rachis scaly; pinnae entire, slightly auriculate at the base..... *Pteris vittata*
      3'. Petiole and rachis glabrescent or with few hairs and scales at the base; pinnae not auriculate at the base.
         4. Medial pinnae usually entire, rarely divided.
            5. Laminae chartaceous to semicoriaceous; pinna-base asymmetrical, attenuated to subdecurrent, not forming noticeable wings along the rachis; abaxial laminar tissue without venuloid idioblasts .....*Pteris cretica*

5’. Laminae papyraceous, delicate; pinna-bases decurrent, forming wings along both sides of rachis; abaxial laminar tissue with venuloid idioblasts ..... *Pteris multifida*

4’. Medial pinnae usually divided.

6. Fronds dimorphic .....*Pteris ensiformis* var. *victoriae*

6’. Fronds monomorphic.

7. Medial pinnae pinnatisect, segments oblong with an obtuse apex ....*Pteris plumula*

7’. Medial pinnae pinnate, segments elliptic-lanceolate with and attenuate apex..... .....*Pteris semiadnata*

2’. Laminae basally ternate.

8. Laminae elliptic to ovate-deltate;segment margins crenate ..... *Pteris famatinensis*

8’. Laminae deltate; segment margins dentate or serrate.

9. Costae abaxially with antrorse, whitish, tiny spines .....*Pteris inermis*

9’. Costae without antrorse whitish spines.

10. Segments with an obtuse apex and dentate margin; pseudoindusia short, slightly raised .....*Pteris exigua*

10’. Segments with an acute apex and margin serrate; pseudoindusia flattened, extended almost to the entire margin..... *Pteris deflexa*

1’. Venation areolate.

11. Laminae hirsute, hairs with acute apex, translucent to reddish ..... *Pteris lechleri*

11’. Laminae glabrous or with hairs with obtuse apex, translucent to whitish.

12. Laminae pilose, veins anastomosing to form 2–3(–4) rows of areoles along each side of midrib .....*Pteris sotae*

12’. Laminae glabrous, veins anastomosing to form 4–5 rows of areoles along each side of midrib.

13. Rachis narrowly winged.....*Pteris denticulata*

13’. Rachis without wings .....*Pteris brasiliensis*

Pteris ensiformis Burm. f. **var. *victoriae*** Baker, Gard. Chron., ser. 3, 7: 576. 1890. Figs. 1; 2

Plants terrestrial. Rhizome creeping, with basifixed scales, these concolorous, dark-brown, bright. Fronds dimorphic; petiole adaxially sulcate 1/2–2/3 of the total length frond, mostly straw-colored, glabrous or with few basal scales; laminae ovate-oblong to lanceolate, imparipinnate, 1–2 pinnate, medial pinnae usually divided; pinnae shortly petiolulate, shorter towards the distal portion, ensiform, with a long-linear tip, and three or four distant pairs of sessile pinnulae; venation 1-furcate, with white bands extending from the midrib nearly to the edge of segments. Sterile laminae shorter than the fertile, 18.4 × 6.4 cm, apex pinnatifid ; pinnulae generally wider than fertile ones, 1.2–(2.1)–3.4 cm × 0.7–(0.8)–1 cm, oblong, with serrate margin and round to obtuse apex. Fertile laminae 34–36 × 15.5 cm, apex conform; pinnulae 1.1–(4.2)–12.5 cm × 0.4–(0.47)–0.7 cm, linear, more markedly ensiform than sterile and with white bands more conspicuous, margins entire except occasionally at the serrate apex, acute; coenosori subterminal to terminal; pseudoindusia whitish; spores trilete, ornamented with conical projections, equatorial cingulum present. 64 spores per sporangium (non-apogamous).

Gutiérrez *et al*. 1638 (BA) has laminae with incomplete sterile-fertile leaf dimorphy. It has sterile pinnae in the proximal portion, fertile in the distal portion; pinnae with intermediate characteristics in the middle portion of the lamina were observed (Fig. 2a).

Observed material: ARGENTINA. MISIONES: Depto Iguazú, Puerto Bossetti, ex Pcom, Cuartel Paulito, 27.VIII.2003, *Keller & Moskovich 2337* (CTES); Puerto Iguazú, Reserva Municipal Iryapú, 27.II.2021, *Marquez et al. 741* (SLP); Dpto. Libertador General San Martín, Puerto Rico, dentro de una plantación de *Pinus elliotii*, 28.III.2023, *Castía 315* (SLP); Dpto. San Ignacio, RN 12, 2 km S de San Ignacio, orilla N del puente, 22.II.2020, *Gutierrez et al. 1638* (BA).

Currently three (Fraser-Jenkins *et al.* 2017; Hassler 2018) or four varieties (Zhang *et al.* 2013) of *P. ensiformis* are formally recognized depending on the taxonomic treatment followed. Specimens found in Argentina belong to *P. ensiformis* var *victoriae*, which is distinguished from others by having white bands extending from the midrib nearly to the edge of segments. Some authors have identified it as a cultivar, similar to other varieties

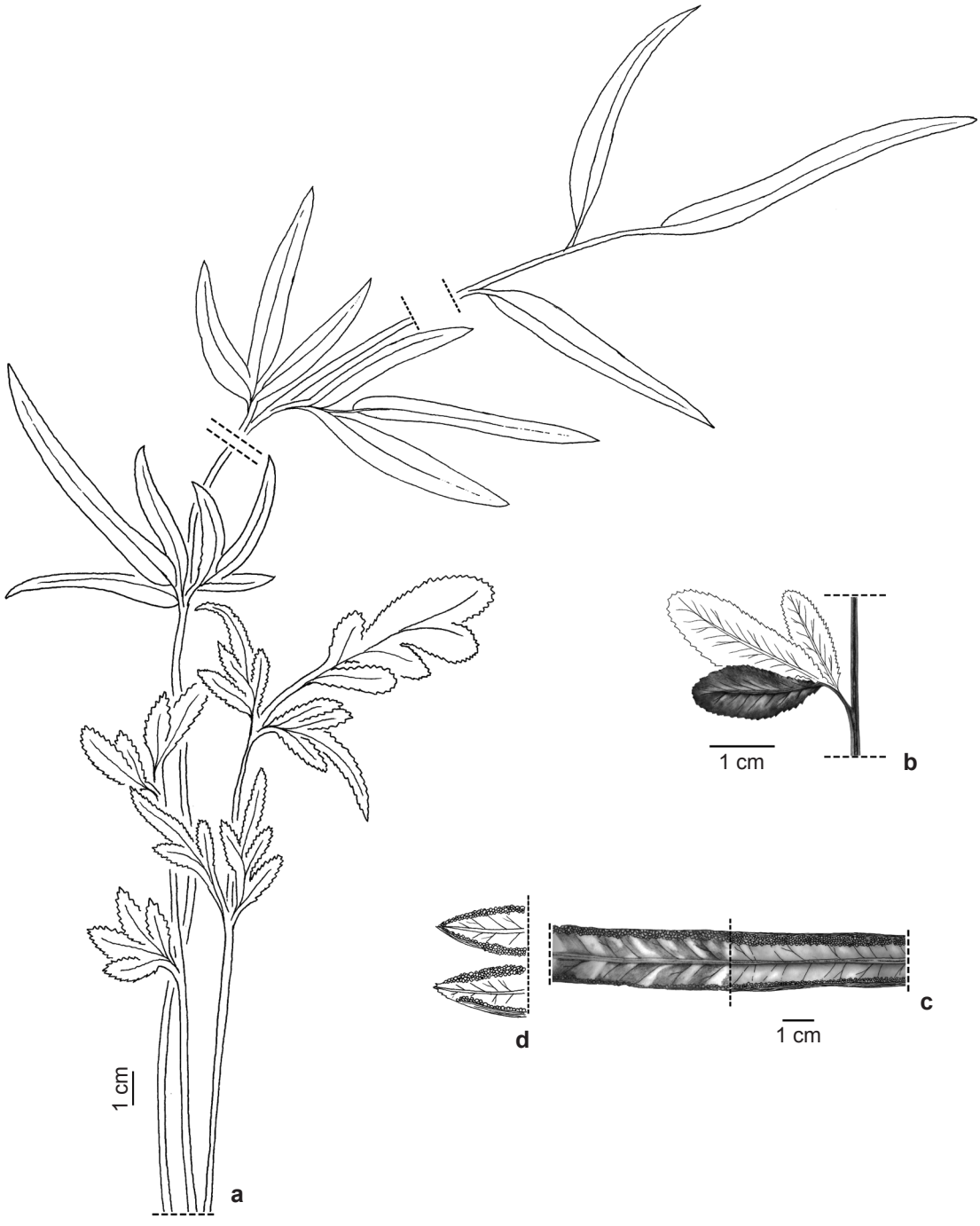

Figure 1 – a-d. Illustration of *Pteris ensiformis* var. *victoriae* – a. general aspect showing a fertile and two sterile fronds; b. detail of adaxial face of sterile pinnae, basiscopic segment showing white bands pattern; c. detail of abaxial face of fertile segment in the middle portion, left side show white bands pattern, right side show 1-furcate venation; d. details of terminal portion of two different fertile segments observed, bearing sporangia to the apex (above) or subapically (bellow). Illustrated specimen: (a-d. Gutiérrez *et al*. 1638).

of commercial origin such as "Evergemiensis" (Martinez 2011).

Review of *Pteris ensiformis* distribution: herbarium collections *vs.* iNaturalist observations

Since the populations found in Argentina were already treated in the previous section, they will not be discussed here, but they are considered in the numerical summary of the records.

In order to carry out the distribution analysis, the species was considered without distinction between varieties. Of 109 total records (herbarium plus iNaturalist observations) found in South America, 6 belong to var. *ensiformis*, 92 to var. *victoriae*, and 11 could not be identified by photographs of the specimens (Fig. 3a). Among total records, only 76 were considered for the distribution analysis because they come from non-cultivated plants. When discriminating the

Figure 2 – a-d. *Pteris ensiformis* var. *victoriae* found in Misiones (Argentina) – a. general aspect; b. detail of abaxial (forward) and adaxial (back) side of fertile segment showing white bands running from the midrib nearly to the edge of segments. Cenosorus protected by marginal pseudoindusium; c. adaxial side of rachis showing sulcus; d. detail of sterile oblong segment showing dentate margin. (a-d. *Gutiérrez et al. 1638*). Scale bars: b-d = 2 mm.

records according to the information resource used, there is a lower number of populations supported by specimens deposited in herbariums (25) than those registered in iNaturalist (51), which seems to indicate a underrepresentation of the species data in the collections (Fig. 3b). This is accentuated when the distribution is evaluated by country since areas where the species was not previously cited can be identified.

The country with the highest number of herbaria records was Brazil (21). The distribution pattern of populations is markedly eastern, being present in localities near the coast of the states of Santa Catarina, Parana, São Paulo, Rio de Janeiro, Minas Gerais, Bahia, Pernambuco and Paraíba; and with some records in northern states such as Maranão and Pará. The observations contributed by the community in iNaturalist (35) showed a similar distribution pattern for the species, but allowed to identify populations present in localities of two new states: in suburban areas of Maceio (Alagoas state), and in Manaus (Amazonas state). This last record is separated from the rest of the distribution, in the center of the country.

Considering only the data from herbarium collections, there are no records of *Pteris ensiformis* growing out of cultivation in the rest of South American. There are specimens deposited in the US, NY and CSD from plants under cultivation in Ecuador and French Guiana, and specimens of dubious nature from Colombia deposited in CDMB and CUVC (Tab. 2). However, the iNaturalist data studied suggest that the species grows spontaneously in these and other countries.

In this way, three community observations were recorded in Ecuador from 2020 to 2023, one of which belongs to a specimen growing within the natural reserve "Bosque La Perla" in La Concordia (Santo Domingo de los Tsáchilas province). For French Guiana, five records were photographed in suburban areas of the commune of Remire-Montjoly (north of the country) and of the commune of Saül (center of the country).

For Colombia, five individuals were recorded growing in urbanized areas of the surroundings of urban centers, such as the city of Medellín (Dto. Antioquia), Bucaramanga (Dto. Santander), and Villavicencio (Dto. Meta) .

Only from community observations it was possible evidenced the presence of *Pteris ensiformis* in Trinidad and Tobago. The two observations were taken in urbanized areas of San Juan city and Arima. The species was previously mentioned by Golding & Ackers (2004) in their chronicle of the British Pteridological Society field excursion to Trinidad in January 2004. According to the authors, a population corresponding to the variety "victoriae" was observed growing in Soho Caves, located in upper Aripo Valley. The authors stated that they consulted specimens in the National Herbarium of Trinidad and Tobago, but found no collections of *P. ensiformis* was found there.

Finally, an observation record originated in 2020 was found for Paraguay in Santa Rosa city (Dto. Itapúa).

The only records of the species that could not be corroborated were those cited in the bibliography for Chile. Although Macaya (2008) mentions *P. ensiformis* as a cultivated species in that country, he does not cite specimens and no records of the species have been found in herbaria or in the databases consulted. For this reason, the presence of the species in that country could not be corroborated.

In relation to the habitats occupied by the species, in most of the cases specimens were found in areas with an anthropic influence (urbanized areas, roadsides, forest plantations) and, to a lesser extent, in unprotected natural habitats or protected areas (Supplementary information 1, available in Figshare at <https://figshare.com/account/home#/projects/162196>).

Status in the naturalization process of *Pteris ensiformis* in South America

The only country in South America where the information associated with herbarium specimens suggests that there are self-sustaining populations over time is Brazil (Fig. 3c). Although cultivation of the species is recorded through herbarium collections since 1908 in the Pará state, the oldest specimen collected in the country dates from 1905 from Parque Natural Municipal de Porto Velho (Rondônia state). While the status of the latter could not be determined, its presence within a protected area could indicate that the species escaped from cultivation at a similar time to the colonization events cited for Central America (Jones *et al.* 2019). No further evidence has been found of the presence of species in Rondônia, but populations were recorded in Pará state at the end of the 20th century, and they were classified as growing "out-of-cultivation". The latter suggests that the process of colonization of the species in the country takes more than 100 years (Fig. 3d).

In addition to the populations previously identified as naturalizing for Espirito Santo state (Schwartsburd *et al.* 2017), Paraná (Matos *et al.* 2020), and the records out of cultivation observed for Santa Catarina (Funez *et al.* 2017) and Minas Gerais (Miranda 2020), most of the herbarium collections from the states of Bahía, Maranhão, Pará, Paraíba, Río de Janeiro, Rondônia, and São Paulo belong to populations identified as cultivated or escaped from cultivation without evidence of their ability to be self-sustaining. In this sense, the naturalized status for the species in

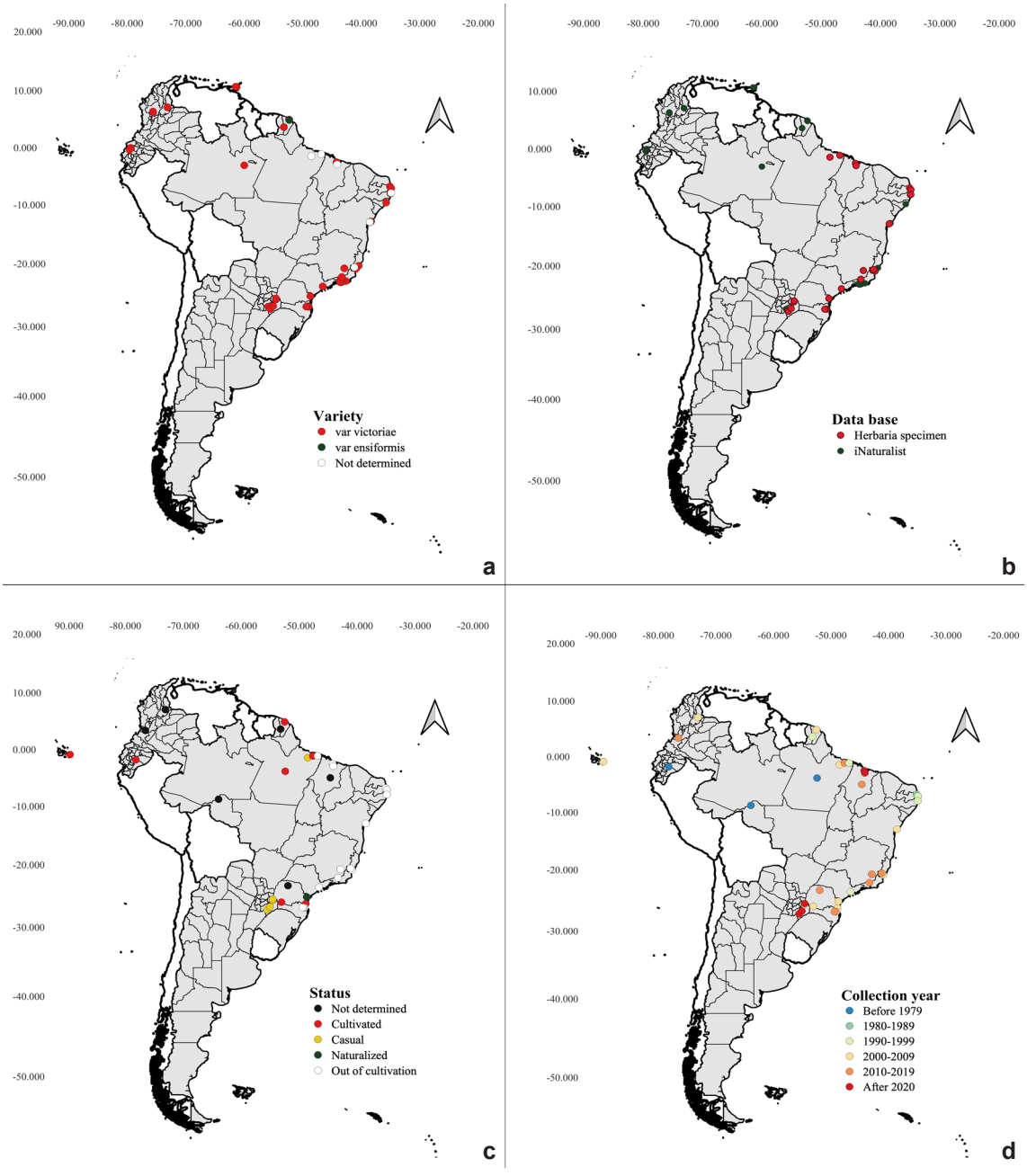

Figure 3 – a-d. *Pteris ensiformis* in South America Countries painted gray are those where at least one record of the species was identified. – a. studied records expressed by variety; b. studied records expressed by database consulted; c. studied records expressed by status assigned in this article; d. studied records expressed by collection year.

Brazil was assigned based on records previously identified in the above-mentioned floristic works.

As mentioned in the previous section, since for Ecuador and French Guiana the records of the species in the herbarium collections come from cultivated plants, that status was assigned to the country. However, it should be reviewed to confirm the aforementioned observations of iNaturalist.

It was not possible to access images of the specimens from Colombia deposited in CDMB, or other label data, so neither the species variety nor the status in the naturalization process of record could be detailed. Because they are collections from a Botanical Garden, it is to be expected that they come from cultivated specimens. Something similar occurred with the collections deposited in CUVC. Although the specimens from the Meléndez University Campus (Universidad del Valle) could be studied, the information on the labellum does not allow us to recognize whether they belong to cultivated species or individuals growing spontaneously outside cultivation.

Conclusion

One of the biggest challenges in determining the stage of the naturalization process of *Pteris ensiformis* from herbarium specimens is the lack of information in the labels about the extent and the proportion of young and adult individuals in the population. This, added to its underrepresentation in botanical collections, makes it difficult to study their introduction and dispersal history as if it could be done in other exotic species such as (Strother & Smith 1970). For this reason, it was difficult to reach conclusions about reproduction over time and the self-sustainability of the populations. Additional studies are necessary to evaluate its dispersal capacity over long distances, another key element to assess the invasion process (Blackburn *et al.* 2011).

Despite the difficulties mentioned in this article it was possible to evidence, from alternative sources of information, that the distribution of *Pteris ensiformis* in South America may be broader than Brazil and Argentina, indicated by the bibliography and herbarium collections. The observations uploaded by the community to citizen science platforms such as iNaturalist proved to be an important source of information. Through this platform it was possible to detect the presence of the species growing outside of cultivation in countries where until now it had not been registered for regional or local flores, such as Colombia (Bernal *et al.* 2016), French Guiana (Boggan *et al*. 1997) and Paraguay (Paraguay Checklist 2016). Although the presence must be supported by specimens deposited in herbaria to have scientific support, geolocalized observations of the community are an excellent starting point for planning future collecting trips. They can also be useful to infer the presence of a species in regions where it was previously mentioned but no associated collections were found, as in the case of populations found in Trinidad and Tobago.

Like other introduced species of the genus such as *P. cretica*, *P. multifida*, *P. vittata*, out-of-cutlivation occurrences of *Pteris ensiformis* appear to be associated with urbanized areas or suburbs. However, unlike what happens with these species, there is little evidence that populations can develop in natural environments, representing a potential invasion. However, it is necessary to monitor populations found within protected areas close to cities or cleared areas, such as those registered for the province of Misiones in Argentina. The direct relationship between the increase in the richness of invasive alien species and changes in land use, housing development, and climate change caused by human activity, has been suggested by numerous authors (Sala *et al.* 2000; Gavier-Pizarro *et al.* 2010). Currently, *P. ensiformis* is only known in Argentina from Misiones province, where 200 exotic taxa are recorded (Zanotti *et al.* 2020).

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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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