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Contributions to the knowledge of *Aptychopsis cylindrothecia* (Sematophyllaceae): an endemic and interesting species from Brazil

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Abstract
Aptychopsis cylindrothecia is an endemic and poorly known species in the country. In the present study, information on its taxonomy, morphology, and ecology is presented. Taxonomic and morphological data were obtained through the analysis of nomenclatural types. For being a little known species with few records, distribution models were used to estimate areas with greater environmental suitability and locate new populations, using MaxEnt. The IUCN conservation status such as the extension of occurrence (EOO) and area of occupancy (AOO) was performed using R software. Two datasets are modeling in this research. The first dataset was using the primarily specimens deposited in herbarium collection. The results of on dataset, provided preliminary data on the most suitable places for its occurrence, thus making it possible to find new populations. The second dataset was performed using the data set1 and new populations were found. Currently, the AOO estimated 52km² and EOO 827.710 km², both estimates classified as Least Concern status. The models indicate the phytophysiognomies of Atlantic Forest in Southwest region of Brazil, preferentially high forest, such as the appropriate areas for the most probable occurrence of the *A. cylindrothecia.* These results could serve as guides for future survey expeditions, understand their ecology, and morphology.

Keywords: Atlantic Forest; Conservation status; Predictive models; Pleurocarpous mosses.

Contribuições ao conhecimento de *Aptychopsis cylindrothecia* (Sematophyllaceae): uma endêmica e interessante espécie do Brasil

Resumo
Aptychopsis cylindrothecia é uma espécie endêmica e pouco conhecida no país. No presente estudo, é apresentado informações sobre a sua taxonomia, morfologia e ecologia. Os dados taxonômicos e morfológicos foram obtidos através da análise dos tipos nomenclaturais. Por ser uma espécie pouco conhecida e com poucos registros, foram utilizados modelos de distribuição para estimar as áreas com maior adequabilidade ambiental e localizar novas populações, usando o MaxEnt. Também foram analisados o status de conservação da espécie e estimado a extensão de ocorrência (EOO) e área de ocupação (AOO) no R software. Dois conjuntos de dados foram usados para a modelagem. O primeiro conjunto de dados utilizou os dados prévios depositados em herbário. Os resultados desta análise serviram de base para localizar novas populações. O segundo conjunto de dados foi composto pelas informações iniciais mais as novas populações encontradas. Atualmente, a espécie apresenta AOO de 52 km² e EOO 827.710 km², ambas as análises classificam a espécie no status menos preocupante. Os modelos indicam que a espécie pode ser encontrada preferencialmente na Floresta Atlântica, em florestas de altitude no sudeste do país. Os dados aqui apresentados, servem de base para a compreensão no aspecto taxonômico, morfológico e ecológico de *A. cylindrothecia*.

Palavras-chave: Floresta Atlântica; modelagem preditiva; musgos pleurocárpicos; status de conservação.

Introduction

Among Brazilian bryophytic phytogeographic domains, the Atlantic Forest has the highest number of bryophytes, including endemic and endangered species (Costa & Peralta, 2015), and it is considered by some highlanders a center of diversity for mosses and liverworts in Brazil (Gradstein & Costa, 2003; Costa et al., 2011). Moreover, the high diversity of bryophytes in the Atlantic Forest is correlated with environmental and physiognomic conditions that provide a larger number of microhabitats, thus favoring the

establishment of species and providing floristic diversity (Pócs, 1982).

The process of endemism in bryophyte species is explained by Schofield (1985) where the colonization period, environmental diversity, moisture availability, and population isolation time. Some bryophytes may have a reduced distribution because they have strict ecological requirements involving climatic restrictions and dispersal limitations, as well as specific substrate preferences, thereby limiting their occurrence (Frahm, 2008).

Predictive modeling of species distribution has proven to be a promising tool in bryophyte studies, especially for species with restricted ranges, as its main found new populations. In addition to its use to predict potential locations, some studies involving predictive modeling of species include analyses such as habitat preference (Richter, Schutze, & Bruelheide, 2009; Sérgio, Vieira, Claro, & Garcia, 2011), finding potential distribution centers overlapping with Conservation Units (Silva, Kamino & Pôrto, 2014), or assessing the conservation status of rare or endangered species (Barros, Siqueira & Costa, 2012; Inácio-Silva, Carmo & Peralta, 2017).

Aptychopsis is a Neotropical genus comprising ten species, six of them occur in Brazil (Evangelista-dos-Santos, 2023) and three are endemic: *Aptychopsis cylindrothecia* (Broth.) P.E.A.S.Câmara, Carv.-Silva & W.R.Buck, *Aptychopsis pyrrhophylla* (Müll.Hal.) Wijk & Margad., and *Aptychopsis subpungifolia* (Broth.) Broth. The species occurs in the Cerrado, Amazon Forest, and Atlantic Forest Domains (Evangelista-dos-Santos, 2023). This genus present well-developed and numerous alar cells, thick-walled, dark-red or yellow, elongated laminal cells, with a porose at base (Visnadi, 2015; Evangelista-dos-Santos et al., 2020).

Aptychopsis cylindrothecia has only a few records in Brazil, and its geographic distribution taxonomy, and ecology are poorly. It has been mentioned in floras and checklists (Schäfer-Verwimp, 1991; Buck & Vital, 1992; Costa et al., 2011; Yano, 2011; Visnadi, 2015). However, in most works there is only the citation of the nomenclatural type and the sample cited from Espírito Santo by Schäfer-Verwimp (1991). The information about ecology, morphology and, taxonomy about this species is little know.

Therefore, the use of models in biogeographic and conservation studies of rare and/or endemic species is fundamental to fill the gaps in the knowledge of their distribution. Thus, the objectives of our study were to model the potential distribution of *A. cylindrothecia*, providing the expansion of the biogeographic knowledge of the species, find priority areas of occurrence, and analyze its ecological requirements based on the characterization of these locations with high probability of occurrence. The morphological diagnosis and illustration of *A. cylindrothecia* are provided.

Materials and Methods

All registers of occurrence of *A. cylindrothecia* in Brazil were based on specific literature (e.g. Schäfer-Verwimp, 1991; Buck & Vital, 1992; Visnadi, 2015), Species Link (https://specieslink.net/search/), Global Biodiversity Information Facility GBIF (https://www.gbif.org/), and herbarium samples (CEPLAC, MBM, NY, UB, and HUEFS). The samples were confirmed by morphological analyses of nomenclatural types, as well as diagnosis and illustrations presented here. The nomenclature was updated by Carvalho-Silva et al. (2017).

Information about geographical coordinates were obtained from exsiccates samples. All coordinates are checked and confirmed with information about the collected samples in ArcMap software. The ArcGis program was used to create the distribution maps and the species' range maps, which were based on the consensus models (following Maximum Sensitivity Plus Specificity threshold). All shapefiles and geographical information were obtained from the IBGE (Instituto Brasileiro de Geografia e Estatística) database.

We used two datasets from the collection records. For the first time, known five primarily and confirmed points were analyzed for modeling and conducted to find new populations. Find the preliminary potential distribution of *A. cylindrothecia*, new populations were search in specimens deposited in herbarium, this resulted in nine new populations. The second dataset was made up by the records in the first dataset, comprises 14 unique point records (table 1).

Table 1. Records of *Aptychopsis cylindrothecia* (Broth.) P.E.A.S. Câmara, Carv-Silva & W.R. Buck in Brazil. The five previously known points of occurrence marked with asterisk (*).

Nº	Herbarium	Latitude	Longitude	Locality
1	NY	-20.03	-43.5	Santa Bárbara, Serra do Espinhaço – MG
2	UB	-19.959400	-43.415298	Santa Bárbara, Serra do Espinhaço – MG*
3	UB	-20.515	-41.089166	Castelo, Parque Estadual do Forno Grande – ES*
4	UB	-19.935600	-40.600299	Santa Teresa, Estação Biológica Santa Lúcia – ES
5	NY	-21.67	-43.93	Lima Duarte, Serra do Ibitiboca – MG
6	UB	-21.8425	-43.793055	Lima Duarte, Serra do Ibitiboca – MG*
7	UB	-19.217222	-43.506944	Rodovia MG 010, Serra do Cipó – MG
8	UB	-19.227777	-43.486944	Rodovia MG 010, Serra do Cipó – MG
9	UB	-19.215555	-43.490833	Fazenda Palmital, Serra do Cipó – MG
10	CEPLAC	-24.266667	-48.416667	Guapiara, Serra da Paranapiacaba – SP
11	MBM	-29.760299	-51.147201	São Leopoldo, Vila Gonzaga – RS
12	HUEFS	-21.049999	-49.680000	José Bonifácio, fazenda Jacaré – SP*
13	HUEFS	-12.75	-39.7	Santa Terezinha, Serra da Jibóia – BA
14	MBM	-25.534700	-49.206401	São José dos Pinhais, Rio Capivari – PR*

To prediction model the most suitable habitats in which *A. cylindrothecia* can be found, Pearson correlation tests were performed in R to avoid multicollinearity of environmental variables, with a cut-off value of 0.7 (Dorman et al., 2013). Eight environmental layers were used: BIO1, BIO10, BIO11, BIO12, BIO13, BIO17, BIO19, and alt. (table 2). Climatic variables were obtained from WorldClim project (2016), with 30 arc. sec resolution with approximately 1 km² of spatial resolution. Highly correlated layers were excluded from the model based on ecological relevance, thus reducing the chance of overfitting the models.

Table 2. Abbreviations and descriptions of the 20 bioclimatic variables used for modelling the distribution of *Aptychopsis cylindrothecia* (Broth.) P.E.A.S. Câmara, Carv-Silva & W.R. Buck. The bioclimatic used in this study are given in bold.

Bioclimatic variable	Description
Alt	Altitude
BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp)
BIO3	Isothermality (P2/P7) (*100)
BIO4	Temperature Seasonality (standard deviation *100)
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range (P5-P6)
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

Moreover, analyzes of the potential distribution of the species were performed using the Maximum Entropy (Maxent) algorithm (Phillips et al., 2006). The bootstrap resampling method was performed for each species due to the low number of occurrence records, and the number of interactions (100) and threshold (0.00001) followed the recommendations for the program (Phillips et al., 2006). Response curves were also calculated for the variables and the contributions of each environmental variable to the model. The quality of the models was validated based on the AUC value that measures the discriminatory capacity of the random prediction model (Phillips, Anderson & Schapire, 2006), and AUC values considered optimal in this study were those above 0.7, according to Manel, Williams & Ormerod (2001).

Complementary analyses of overlapping data about the occurrence of *A. cylindrothecia* with conservation units, phytogeographic domains, and priority areas for conservation were carried out using the DIVA-GIS software v.5.2, which also allowed the observation of the potential distribution of the species.

Assessment of IUCN (2019) conservation status was assessed using R software with known species data. The construction of Extension of Occurrence (EOO) and Area of Occurrence (AOO) were obtained with ConR package (Dauby *et al*., 2017) in R (R Core Team 2022), as this tool allows the statistical assessment of threat levels by integrating information from protected areas and population formation.

Results and Discussion

Aptychopsis cylindrothecia (Broth.) P.E.A.S. Câmara, Carv.-Silva & W.R.Buck, Taxon 66(4):823. 2017. ≡ *Rhaphidostegium cylindrothecium* Broth., Denkschr. Akad. Wiss. Wien, Math.-Naturwiss. KI. 83: 341. 1924. ≡ *Sematophyllum cylindrothecium* (Broth.) W.R. Buck & Schäf.-Verw., Hattori Bot. Lab. 69:162. 1991. Type: Brasil, São Paulo, São Bernardo, *Schiffner V.F. 1846* (Holotype H-BR ; Isotypes NY [barcode NY01179095!], W [barcode W0074333, photo!]).

Gametophytes medium-sized, yellow-golden to green, ca. 6 cm long; stems creeping to pendent, ascending to erect-ascending; leaves lanceolate, concave or plane, ca. 1.4 – 1.6 mm long; apex acuminate; margins entire or serrulate at apex; costa short and double or absent; cells linear-flexuose, thick-walled, prorulose at base and linear to linear-flexuose at apex of leaves; alar cells yellow, enlarged and inflated or not, oblong; supra alar cells sub-rectangular, in 1 – 2 rows, hyaline. Setae elongate, smooth 0.5 – 0.7 cm long; capsules cylindric to long-cylindric, 1.2 – 1.4 mm long; exothecial cells rectangular, collenchymatous; operculum long-rostrate; exostome teeth triangular, not bordered, median line in zig-zag, cross-striolate below, coarsely papillose above, trabeculate at back; endostome with a low basal membrane, segments papillose, perforate, almost as long as the teeth, cilia absent.

Selected material examined: Bahia: Santa Teresinha, Serra da Jiboia, 04.III.2001, *Valente 51p.p.* (HUEFS). Espírito Santo: Castelo, Parque Estadual Forno Grande, 06.X.2016, *Henriques 760* (UB); Castelo, 19.VIII.1987, *Hatschbach & Cervi 51305* (MBM); Santa Teresa, Estação Biológica de Santa Lúcia, 17.IX.2013, *Sousa 724* (UB). Minas Gerais: Lima Duarte, Serra do Ibitipoca, 20.10.1994, *Buck 26519* (UB); Santa Bárbara, Serra do Espinhaço, Parque Nacional do Caraça, 22.X.1994, *Buck 26632* (UB); Serra do Cipó, Parque Nacional da Serra do Cipó, 12.VI.2009, *Soares 237* (UB). Paraná: São José dos Pinhais, Rio Capivari, 20.VI.1975, *Sehnem 76* (MBM); São Paulo: Guapiara, Serra da Paranapiacaba, Fazenda Intervales,

24.VII.1991, *Vital & Buck 20469* (CEPLAC); São Bernardo, 9.IX.1901, *Schiffner V.F. 1846* (NY).

The shape of capsule and the basal membrane of endostome (Fig. 1) is the best morphology character used to identify *Aptychopsis cylindrothecia* and distinguish to another species of *Aptychopsis.* When absent, the morphology of gametophyte is similar to *A. tequendamensis* (Hampe.) P.E.A.S. Câmara, Carv.-Silva & W.R.Buck. However, the leaves in *A. tequendamensis* are triangular to lanceolate, alar cells slowly differentiated, and laminal cells linear to long rhomboidal at apex (Buck, 1998).

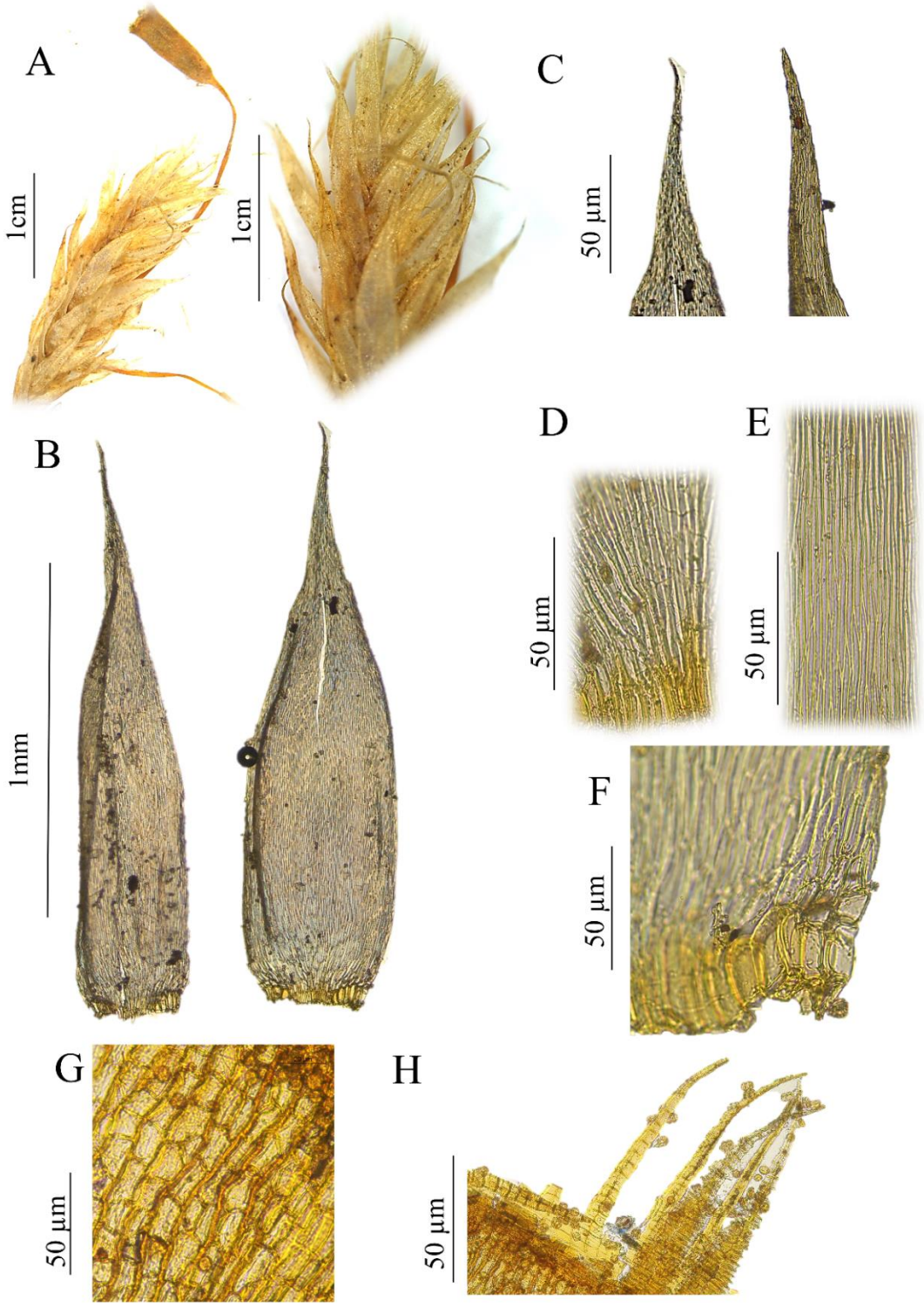

Figure 1. *Aptychopsis cylindrothecia* (Broth.) P.E.A.S. Câmara, Carv-Silva & W.R. Buck. A. Branches. B. Leaves. C. Apex of Leaves. D. Basal cells of leaves. E. Median cells of leaves. F. Alar cells. G. Cells of capsule. H. Peristome. From Isotype (NY01179095!)

Aptychopsis cylindrothecia growing on trees, alternating moist and dry vegetation over sandstone or humid forest with growing in bamboo species however, it is not exclusively distributed in such habitats. According to Buck e Vital (1992) *A. cylindrothecia* grows associated with *Pterogoniopsis paulista* (Buck & Vital) Carv.-Silva, P.E.A.S. Câmara & W.R. Buck other endemic species of the Sematophyllaceae family and restricted to the southeastern region of the country (Buck & Vital, 1992).

Here we confirm the occurrence in the states of Bahia, Espírito Santo, Minas Gerais, Paraná, Rio Grande do Sul, and São Paulo. In this study, was re-established and recognized as an endemic species with a moderate distribution. The study of endemic species and their few occurrence records are frequently the targets of conservation initiatives due to the vulnerability and risk of extinction (Scarano, 2009).

The distribution models developed in Maxent showed AUC values above 0.8, which demonstrates a good performance for the models generated with the Brazilian background. Models with AUC values close than to 1 represent areas with the most likely ecological niche for the occurrence of the species according to the variables used in the model (Phillips et al., 2006).

The variables made different contributions to the models, with precipitation of driest quarter (bio 17), mean temperature in the warmest quarter (bio 10), and altitude (alt) being the most contributed (fig 2). The decreasing order of contribution of the bioclimatic variables to the generated models are: bio 17 (26.7%), bio 10 (20.2%), altitude (18.3%), bio 13 (13.3%), bio 1 (10.2%), bio 19 (9.9%) and bio 12 (1.3%).

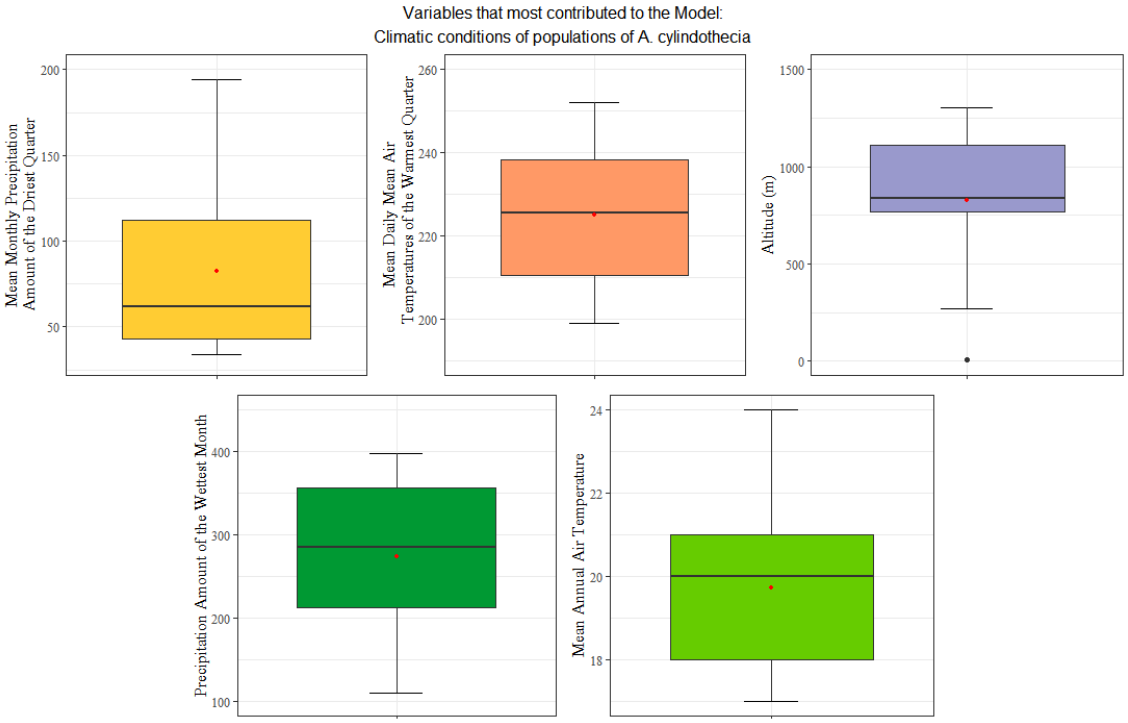

Figure 2. Variables that most contributed to the model.

These models also predict the locations with the greatest suitability for the species, including all known presence points (fig 3). Areas more suitability were recovered from Cadeia do Espinhaço, Chapada Diamantina, Serra do Mar, Serra da Mantiqueira, Serra da Paranapiacaba, and Caparaó National Park (fig 3). These are priority areas for directing new collections or analyzing materials deposited in herbariums.

Aptychopsis cylindrothecia is a species that occurs preferentially in humid environments with low temperature, corresponding to areas of altitude (fig 2 and fig 3). Temperature and precipitation are factors that can influence the distribution of Bryophyte species. This aspect is directly linked to dependence on water in the external environment for the survival and maintenance of physiological processes in bryophytes (Vanderpoorten & Goffinet, 2009). The rainfall variable is more valuable for the distribution of this species because there are no records of its occurrence in open environments because of the exposure to sunlight, and the tack of mechanisms to cope with effects of elevated temperatures.

The areas with the greatest environmental suitability are restricted to the Atlantic Forest domain in ombrophylous forest fragments, which can be explained by the variety of microhabitats, altitudinal gradient and high levels of rainfall and humidity (Batista & Santos, 2016). Moreover, some of these potential locations were concentrated in preserved areas. As they are areas of environmental preservation, they are subject to less human disturbance and contain better conserved flora (Werneck et al., 2011) that provides ideal habitats for the species.

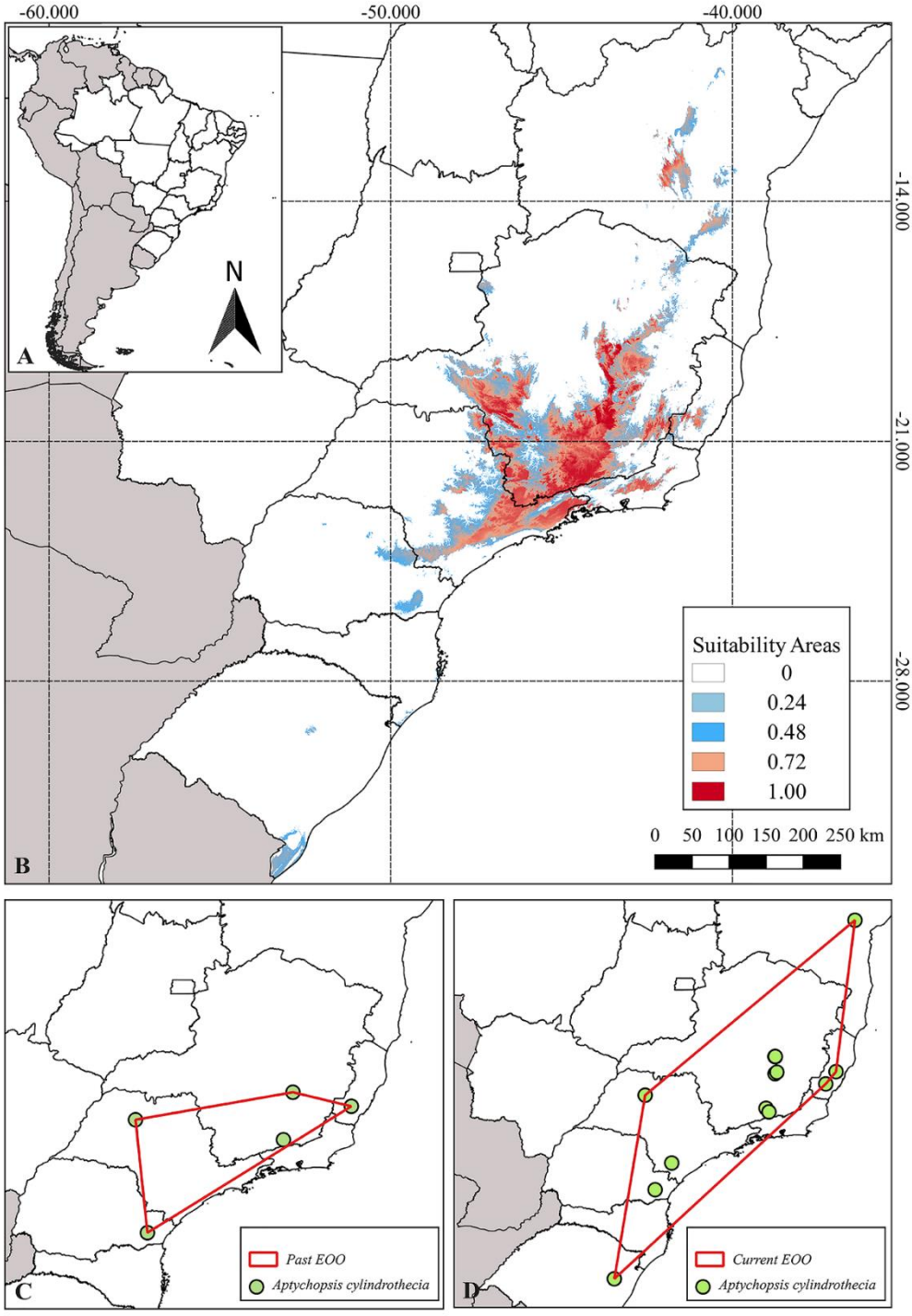

Figure 3. A. Map of South America. B. Areas most suitable for the occurrence of *Aptychopsis cylindrothecia* (Broth.) P.E.A.S. Câmara, Carv-Silva & W.R. Buck. C. Analyze of EOO in the past D. Analyze of EOO with the new populations.

Conservation status of *A. cylindrothecia* was assessed using the five previously known occurrence points. The results obtained from the first data set analysis classified the species as endangered (EN) (fig 3). A change in the conservation status of the species that was possible due to the use of distribution models with previously known data. This analysis provided the direction for finding new populations.

Currently, this species is currently classified as Least Concern (LC) (fig 3). The currently data on the conservation status of the species are summarized in Table 3. New populations were mostly found in materials deposited in herbariums from recent collections or from old materials with generic identification (e.g. *Sematophyllum* Mitt.). Studies on the conservation status of bryophyte species in Brazil began this century, carried out by Costa (1999). According to Costa e Santos (2009), habitat fragmentation and destruction represent the greatest threats to species with

restricted and/or endemic distributions.

Table 3. Assessment of the conservation status of the species *Aptychopsis cylindrothecia* (Broth.) P.E.A.S. Câmara, Carv-Silva & W.R. Buck.

Nº of points	EOO	AOO	Category	Category code
05	260536	20	EN	EN B2a
14	827710	52	LC	LC B1a+B2a

Integrative studies being developed on this Brazilian species of *Aptychopsis* made it possible to identify *A. cylindrothecia*, a species that was neglected in Brazilian Flora for a long time. The data presented here highlight the importance of these studies in the conservation and maintenance of bryophyte diversity.

Conclusion

The data presented here increase the importance of integrative studies as a tool for taxonomic studies. With the use of distribution models, it was possible to find new populations deposited in herbarium as well as to guide future excursions. In this way, a species little known and with few records of occurrence, now has a moderate occurrence in the country. The taxonomic and morphological information will serve as tools for the correct identification and knowledge of *A. cylindrothecia* in the country.

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