Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales. 2025
doi: https://doi.org/10.18257/raccefyn.3095

Natural Sciences

Original article

Expansion of the distribution range and ecological niche modeling of *Philodendron asplundii* (Araceae) in South America

Expansión del rango de distribución y modelamiento del nicho ecológico de *Philodendron asplundii* (Araceae) en América del Sur

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Abstract

Philodendron (Araceae) is one of the richest ornamental genera in the Neotropics, comprising over 600 species. Here, we report the expansion of the eastern distribution of *Philodendron asplundii* with a new record from the Brazilian state of Pará. We present a detailed morphological description and images of *P. asplundii*, an updated distribution map, and the results of the ecological niche modeling of the species based on bioclimatic data and the Maxent, Bioclim, Random Forest and Support Vector Machine algorithms (Ensemble Model). *Philodendron asplundii* occurs in Brazil, Colombia, Ecuador, French Guiana, Perú, and Venezuela. The ecological niche model indicated that *P. asplundii* has a higher probability of distribution in the northern region of South America, mainly in the central and northwestern part of the Amazon. The model also suggested high habitat suitability in Ecuador's areas of Andean forests, and in Northern Guyana. These suitable areas for the occurrence of *P. asplundii* are located in regions with high risk of forest cover loss due to anthropogenic activities. Thus, conservation plans are necessary to avoid the loss of appropriate habitats for the species.

Keywords: Aroids; eastern Amazon; ecological niche; nomadic climber; species distribution modeling; tropical forests.

Resumen

Con más de 600 especies, *Philodendron* (Araceae) es uno de los géneros ornamentales más ricos del Neotrópico. Reportamos la expansión de la distribución oriental de *Philodendron asplundii* con un nuevo registro en el estado brasileño de Pará. Presentamos una descripción morfológica detallada e imágenes de *P. asplundii*, un mapa de distribución actualizado y los resultados del modelado del nicho ecológico de la especie basado en datos bioclimáticos y en los algoritmos Maxent, Bioclim, Random Forest y Support Vector Machine (Ensemble Model). *Philodendron asplundii* está presente en Brasil, Colombia, Ecuador, Guayana Francesa, Perú y Venezuela. El modelo de nicho ecológico indicó que *P. asplundii* tiene una mayor probabilidad de distribución en la región norte de Sudamérica, principalmente en la parte central y noroccidental de la Amazonía. Sugirió, asimismo, una gran idoneidad de hábitat en áreas de bosques andinos en Ecuador, y en el norte de Guyana. Las áreas señaladas como adecuadas para *P. asplundii* se ubican en regiones con alto riesgo de pérdida de cobertura forestal debido a actividades antropogénicas. Por ello se requieren planes de conservación que eviten la pérdida de hábitats apropiados para la especie.

Palabras clave: aroides; Amazonía Oriental; nicho ecológico; trepadora nómada; modelado de distribución de spécies; bosques tropicales

Citation: da Silva-Luz AL, *et al*. Expansion of the distribution range and ecological niche modeling of *Philodendron asplundii* (Araceae) in South America. Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales. 2025 Ago 19. doi: https://doi.org/10.18257/raccefyn.3095

Editor: Carolina Romero

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Received: October 28, 2024
Accepted: July 14, 2025
Published on line: August 19, 2025

Introduction

The Araceae is the third largest family of monocotyledons in the world, with more than 3,600 species distributed in 143 genera (**POWO**, 2024). It has a cosmopolitan distribution, with wide occurrence in humid tropical forests, especially in South America and Central America, where about two-thirds of the species show high rates of endemism (e.g., 50% in Costa Rica and 95% in Panamá) (**Croat**, 2019; **Croat & Oriz**, 2020; **POWO**, 2024). The morphological diversity of the family is attributed to the different sizes of the individuals and leaves, the varied life forms (floating aquatic, terrestrial, arborescent herbs, epiphytes, and nomadic climbers) and the numerous strategies of pollination and fruit dispersal (**Croat & Oriz**, 2020; **Haigh *et al.***, 2020).

Among the Neotropical genera of Araceae, *Philodendron* Schott is one of the most remarkable, with 621 species, standing out for the abundance of individuals in the sites where they occur (**Canal *et al.***, 2018; **Croat & Oriz**, 2020; **POWO**, 2024; **Sakuragui *et al.***, 2024). Plants of the genus are widely used for ornamental purposes due to the morphological characteristics of the leaves (conspicuous size and shape), ease of cultivation, and tolerance to indoor environments (**Klanrit *et al.***, 2023). Although abundant and economically important, it is estimated that at least half of the *Philodendron* species are yet to be discovered due to collection gaps in regions of South America (**Croat & Oriz**, 2020).

During vascular epiphytes inventories in the Eastern Amazon, we found an individual of *Philodendron asplundii* Croat & M. L. Soares in the Brazilian municipality of Capitão Poço, in the northeastern region of the state of Pará. This species occurs in a wide range of elevations and vegetation types in tropical moist forests and premontane wet forests in South America (**Croat & Shah**, 2001). It differs from other *Philodendron* species by its network of fibrous cataphylls and leaf blades with prominent primary veins (**Croat & Shah**, 2001; **Croat *et al.***, 2019). We report here the first record of *P. asplundii* from Pará, expanding its distribution in Brazil, particularly to Eastern Amazon. We also assessed the potential distribution of the species using models to identify the environmental factors determining the spatial distribution of *P. asplundii* in South America.

Materials and methods

Part of the *P. asplundii* individual found in Capitão Poço was collected in September 2023, and the remaining part in April 2024. For species identification, we performed the morphological analyses of fresh and dry materials using a stereoscopic microscope, and we consulted the species' protolog (**Croat & Shah**, 2001), the identification key of *Philodendron* from Brazil (**Sakuragui *et al.***, 2024), and an expert in the Araceae family (see Acknowledgments). The collected materials were herbarized according to **Fidalgo and Bononi** (1989) and deposited in the MG herbarium (acronym according to **Thiers**, 2024). We present a morphological description of *P. asplundii* based on the material collected in Pará and photographs of the specimen, highlighting the diagnostic morphological characteristics of the species (**Figure 1**).

We collected the information on the occurrence of the species from Gbif (https://www.gbif.org/), Jabot (http://jabot.jbrj.gov.br/), Reflora (https://reflora.jbrj.gov.br/reflora/), and Specieslink (https://specieslink.net/search/) databases to generate a distribution map and model the potential distribution of *P. asplundii*. We removed duplicate data, data with no available coordinates, and data with imprecise coordinates, such as those of institutions or municipality centroids, as they could bias the model (**Zizka *et al.***, 2019). With the aid of the R packages spThin and CoordinateCleaner, we identified 214 records of *P. asplundii* with valid coordinates out of the 1,260 records found in the abovementioned databases (**Aiello-Lammens *et al.***, 2019; **Zizka *et al.***, 2019).

We used a set of 19 bioclimatic variables related to temperature and precipitation with a resolution of 10 arc-minutes (Bio1 to Bio19) and elevation information from the World Clim platform (https://www.worldclim.org/) for *P. asplundii* ecological niche modeling, establishing South America as a cutout.

To avoid multicollinearity and select the most appropriate predictors, we performed a variance inflation factor (VIF) test to select uncorrelated variables (VIF < 10) and avoid instability in model performance (**Naimi & Araújo**, 2016). This procedure resulted in the selection of seven bioclimatic variables: Bio2 (mean diurnal range), Bio3 (isothermality), Bio4 (temperature seasonality), Bio9 (mean temperature of driest quarter), Bio15 (precipitation seasonality), Bio18 (precipitation of warmest quarter), and Bio19 (precipitation of coldest quarter). Given that genus *Philodendron* species tend to be influenced by elevation, we also included the variable elevation in the models (**Canal *et al.***, 2019). We used the Maximum Entropy (MAXENT) (**Phillips *et al.***, 2006), Bioclim (**Busby**, 1991), Random Forest (**Prasad *et al.***, 2006), and Support Vector Machine (**Guo *et al.***, 2009) algorithms to test the distribution models. To evaluate the performance of the models, we used the area under the curve (AUC) and true skill statistic (TSS) parameters (**Allouche *et al.***, 2006; **Phillips *et al.***, 2006; **Mateo *et al.***, 2011). We calibrated 70% of the training points and 30% of the testing points. From these algorithms, we created an ensemble model by combining the results of individual algorithm models (with a weighted average method to reduce the prediction error and the uncertainty of model selection) (**Dormann *et al.***, 2018).

All modeling processes were implemented in R 4.3.0 (**R CORE TEAM**, 2024) using the “ggspatial”, “sdm”, “raster”, “terra”, and “tidyverse” packages (**Naimi & Araújo**, 2016; **Dunnington *et al.***, 2023; **Hijmans *et al.***, 2023; **Wickham**, 2023; **Hijmans *et al.***, 2024). The occurrence and modeling maps were processed in the QGIS software, version 3.22.5.

Results

Taxonomy

Philodendron asplundii Croat & M. L. Soares. Novon 11: 381, 2001.

Figure 1.

TYPE: ECUADOR, Napo: vicinity of Baeza, 2,500 m, 19-XII-1979, *T.B. Croat 49444* (holotype: MO-2737423-24, digital image!; isotypes: COL, F2308832, INPA272128, K501952, M198999, NY191178, digital image!, QCA, QCNE, US3648011, barcode 01105803, digital image!).

Nomadic climber herb; root ca. 11–15 × 0.2–0.3 cm, reddish when young. Cataphylls 10.4–28.4 cm long, reddish-green when young, brown when mature, forming a persistent network of fibers; stem with internodes 3–10 cm long, internodes generally shorter on shoots with inflorescence; profiles 9.5–11.2 × 0.5–3.3 cm, persistent, reddish when young and brown when senescent, triangular, apex rounded; leaf petiole 36–47 cm long; leaf blade 56–65 × 26–30 cm, when fresh dark green on the adaxial surface and light green on the abaxial surface, lanceolate to oblong, base slightly cordate, apex acuminate, primary veins light green and prominent, lateral, extending to the leaf margin, secondary veins prominent and tertiary veins weakly visible; inflorescence 1 per leaf, axillary and concentrated on the apical leaves; peduncle 5.3–11.3 cm long; spathe 12.5–14.5 × 3.5 cm, light green, with discrete cream-colored veins at the base, constricted, enveloping the spadix; spadix 11.9–14 cm long, cream in pre-anthesis and brown in anthesis; sterile male zone ca. 2.6 × 1.3 cm, cream; fertile male zone ca. 3.2 × 1.7 cm, cream; female zone ca. 3.5 × 2.5 cm, greenish-cream; apical staminode 2–3 mm long, intermediate staminode 3–4 mm long, gynoecium 0.5–1.2 × 0.3–1.1 mm, yellowish, ovoid; ovary yellowish, 4–7 locules, placentation axillary; infructescences with yellowish, polyspermous berries.

New record. Examined material: BRAZIL, Pará, Capitão Poço, Caranandeua, 50 m, 1°40’14.3”S, 47°02’48.4”W, riparian forests in Açu stream, 05-III-2024, fl, fr, *A. L. S. Luz & M. F. S. Souza 118* (MG).

Philodendron asplundii was found in riparian forests on the banks of the Açu stream, 50 m.a.s.l., in the village of Caranandeua, approximately 11 km from the municipal headquarters of Capitão Poço, Pará. Only one isolated and large individual of *P. asplundii* was observed, occurring as a nomadic climber, approximately 2.5–3 m above the ground,

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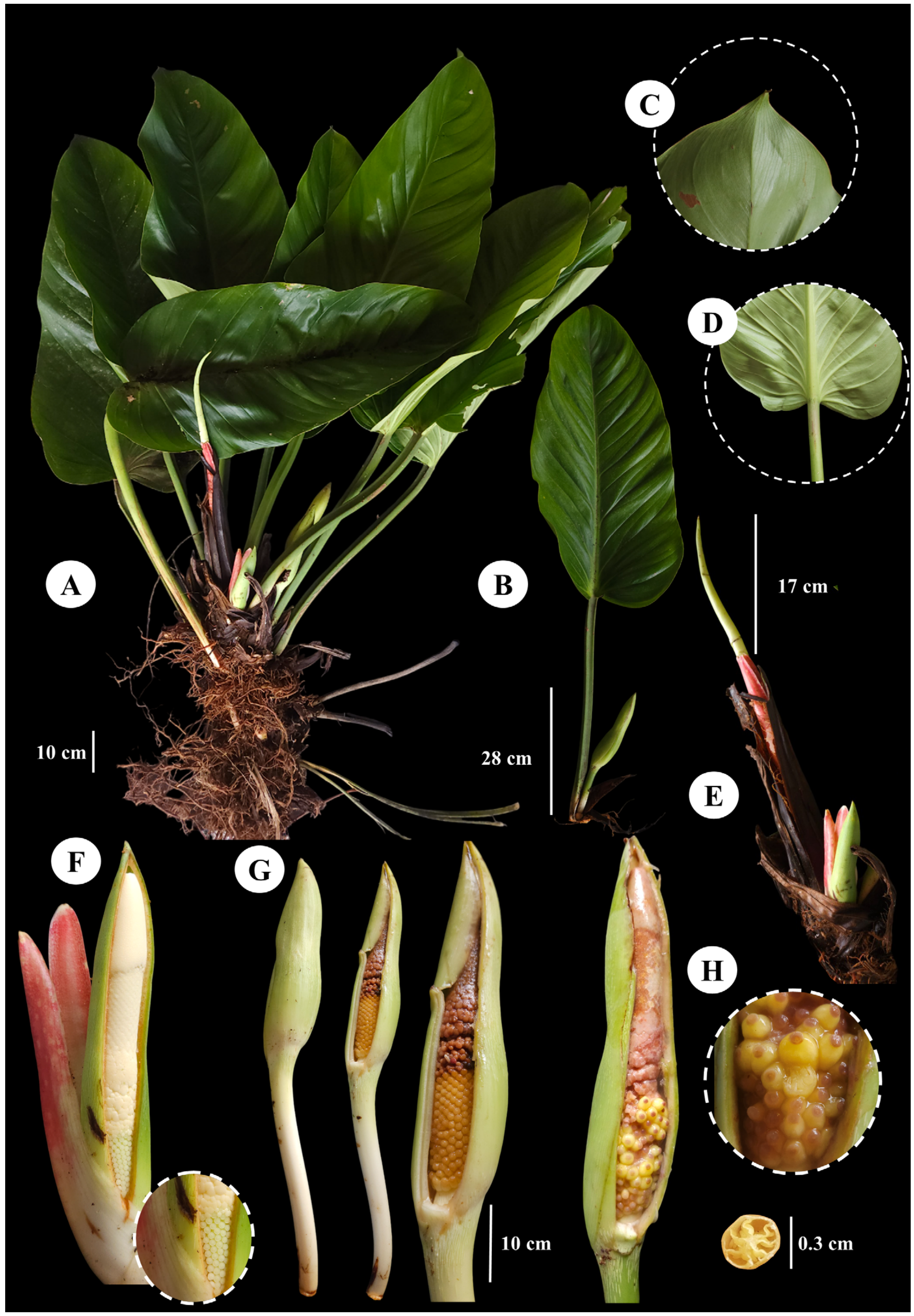

Figure 1. *Philodendron asplundii* Croat & M.L.Soares in the state of Pará, Eastern Amazon, Brazil. **A.** Habit. **B.** Leaf with floral sympodium. **C.** Abaxial surface of the leaf blade, highlighting the apex. **D.** Abaxial surface of the leaf blade, highlighting the base. **E.** Young leaf. **F.** Inflorescence in pre-anthesis. **G.** Inflorescence in anthesis. **H.** Infructescence with details of the berries and cross-section of the fruit showing the locules. Photographs by Ana Laura da Silva Luz

in a humid site exposed to the sun on the bank of the watercourse. The local vegetation consists of floodplain forest with dense stands of buriti palm (*Mauritia flexuosa* L. f. – Arecaceae) and agropastoral crops in the surrounding areas.

Ecological niche modeling

Philodendron asplundii occurs in Brazil, Colombia, Ecuador, French Guiana, Perú, and Venezuela (**Figure 2**). In Brazil, the species had only been recorded before in the states of Amazonas and Amapá. With the present record, the eastern distribution of the species was expanded, with an occurrence record now also in the state of Pará (**Figure 2**).

For *P. asplundii* niche modeling, the Maxent and Random Forest algorithms had the best performances, with AUC and TSS > 0.9 (**Table 1**), that is, the distribution patterns generated by the model agreed with most of the observed data. The Bioclim algorithm had the lowest performance. In general, the bioclimatic variables related to temperature and precipitation had a greater contribution than elevation in the models with different algorithms. The predictors with the greatest contribution to the models were the variables Bio15 (seasonality of precipitation) and Bio3 (isothermality), responsible for the variation in the amount of precipitation and in temperatures throughout the year,

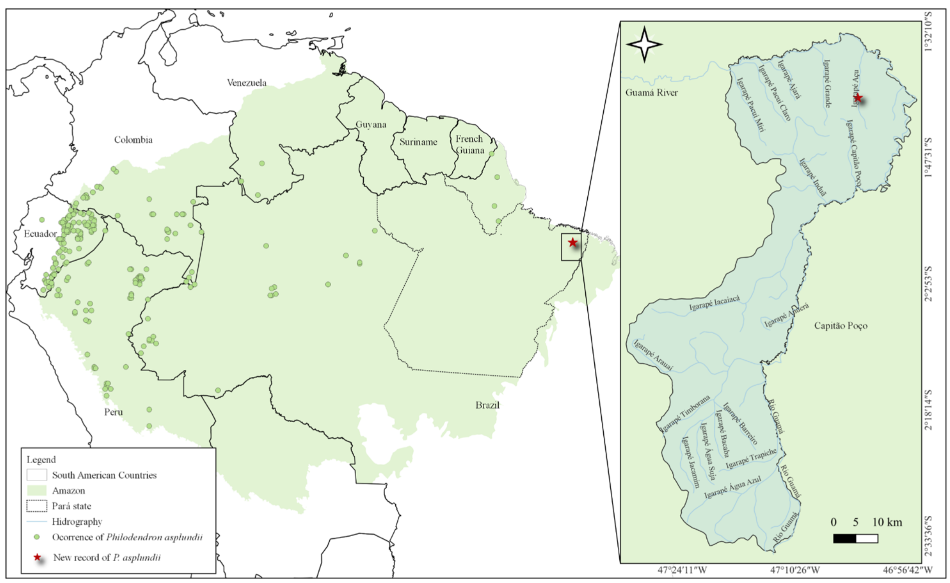

Figure 2. Location map of the new record of *Philodendron asplundii* Croat & M.L.Soares in the municipality of Capitão Poço, state of Pará, Eastern Amazon, Brazil. Map prepared by Ana Laura da Silva Luz.

Table 1. Performance metrics and percentage contribution of bioclimatic variables (based on AUC metrics) in the ecological niche modeling of *Philodendron asplundii* Croat & M.L.Soares

Algorithm	AUC	TSS	Variable contribution (%)							
			Bio2	Bio3	Bio4	Bio9	Bio15	Bio18	Bio19	Elevation
BIO	0.78	0.56	0.3	2.9	34.9	6.8	35.4	0.9	1.1	6.8
MAX	0.95	0.79	30.3	45.1	36.1	20.1	41	15.1	0.2	15.4
RF	0.94	0.76	0.7	2.1	2.2	1.3	5.1	1.2	1.1	1.3
SVM	0.91	0.71	11.9	38.2	6.2	17.6	96.7	16.2	42	15

AUC: area under the curve, TSS: true skill statistic, BIO: Bioclim, MAX: Maxent, RF: Random Forest, SVM: Support Vector Machine. Bioclimatic variables: mean diurnal range (Bio2), isothermality (Bio3), temperature seasonality (Bio4), mean temperature of driest quarter (Bio9), precipitation seasonality (Bio15), precipitation of warmest quarter (Bio18), and precipitation of coldest quarter (Bio19)

doi: https://doi.org/10.18257/raccefyn.3095

respectively. The relative importance of the variables followed this order: Bio15>Bio3>Bio4>Bio9>Bio19>Bio2>Elevation>Bio18. Among the variables with the greatest contribution to the model, isothermality (Bio3) varied between 80% and 90%, indicating that suitable habitats for the species present large thermal variation throughout the year (response curves in Supplementary material, **Figure 1S,** https://www.raccefyn.co/index.php/raccefyn/article/view/3095/4567). Lower seasonality in precipitation (Bio15) and temperature (Bio4) also contributed to the occurrence of the species. The precipitation ranges of the warmest and coldest quarters varied from 400 to 600 mm and 600 to 800 mm, respectively, while the elevation of 0-1,500 m proved to be suitable for the occurrence of *P. asplundii*.

In general, *P. asplundii* ecological niche model was consistent with the known distribution of the species (**Figure 3**). The distribution map generated based on the averages of the models (ensemble) showed that *P. asplundii* has a higher probability of distribution in the northern region of South America, with the central and northwestern part of the Amazon being the areas with the highest probability of occurrence of the species. The model also suggested a high habitat suitability in Ecuador, coinciding with areas of Andean forests.

Northern Guyana and the Colombian Western Andes were also suitable areas for the occurrence of the species, but there are no records of *P. asplundii* in these regions until now. Among the known areas of occurrence of the species in Brazil, the model predicted a low probability of occurrence in the state of Amapá. In the state of Pará, only a small region presented suitable habitats for the establishment of the species, which converges with the area of the new occurrence.

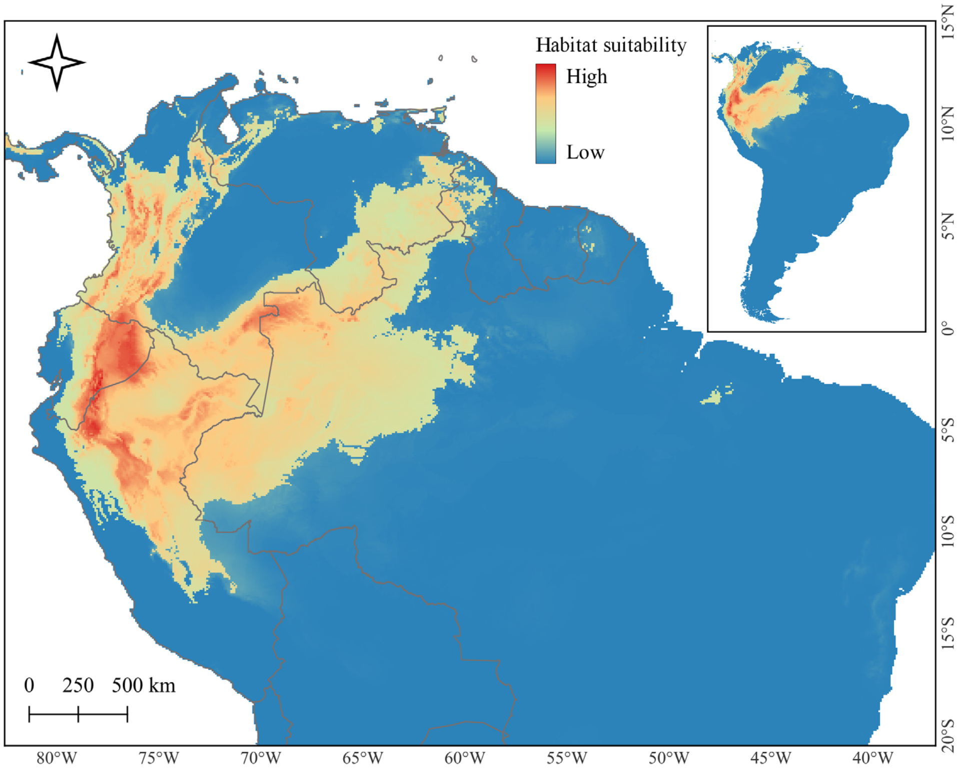

Figure 3. Distribution model of *Philodendron asplundii* Croat & M.L.Soares in South America. Warmer colors indicate a higher probability of occurrence of the species. Map prepared by Ana Laura da Silva Luz

Discussion

Philodendron asplundii was first collected in 1929, but only in 2001, it was described. It is recognized mainly by the stem covered by cataphylls forming a network of fine, dense, and persistent fibers, and by the narrow leaf blades with prominent primary veins (visible in fresh and dry materials) (**Croat & Shah**, 2001; **Beltrán *et al.***, 2019). The shape and size of leaf blades are highly variable. However, leaf venation patterns are consistent and, therefore, reliable diagnostic characters for the identification of *P. asplundii* (**Croat & Shah**, 2001). Overall, the morphology of the newly collected specimen is in line with the species circumscription. Nonetheless, it is noteworthy that we observed only one inflorescence per leaf axil in the Pará specimen, whereas the type specimen has up to eight inflorescences per leaf axil. We recorded the species at a low altitude (50 m.a.s.l.), out of the elevation range reported by **Croat and Shah** (2001), which was 150 to 2,500 m.a.s.l. These morphological and altitudinal variations may reflect intraspecific differences of *P. asplundii* populations in the Amazon. *Philodendron asplundii* can be confused with *Philodendron colombianum* R.E.Schult., but the former has larger leaf blades (vs. smaller ones) and inflorescences with more elongated spathe tubes (vs. shorter and globular ones) (**Croat & Shah**, 2001).

Philodendron asplundii was found in riparian forests, in a region characterized by a high number of freshwater courses regionally known as *igarapés* (meaning “canoe path” in Tupi), which are part of the Guamá River drainage system (**Cordeiro *et al.***, 2017; **Rede Amazônia Sustentável**, 2024). *Igarapés* are the headwaters of micro-basins that flow into rivers and the Amazon basin, with large areas of riparian forests and high species diversity (**Rede Amazônia Sustentável**, 2024). These ecosystems are under pressure and have their integrity affected by human activities that cause the loss of vegetation for agricultural and pastoral purposes and the opening of primary and secondary roads (**Leal *et al.***, 2017; **Faria *et al.***, 2024).

The bioclimatic variables used in the *P. asplundii* ecological niche model showed that seasonality in temperature and precipitation is important for the distribution of the species. However, large changes in temperature and precipitation patterns observed from 1985 to 2021 in the Amazon as a consequence of deforestation may have affected water availability and altered the hydrological cycle of the region (**Moreira**, 2024). Furthermore, significant loss of abundance and richness of tree species are expected in the Amazon (**Gomes *et al.***, 2019) due to climate change, which may also impact the distribution of *P. asplundii* since it is a nomadic climber.

The ecological niche model of *P. asplundii* was consistent with Andean forest areas. Such mountainous areas in the Andes provide important habitats for species of the Araceae family, mainly at elevations between 1,000 and 1,500 m (**Kessler**, 2001; **Leimbeck *et al.***, 2004; **Croat**, 2019), as indicated by the present distribution models of *P. asplundii*. Furthermore, the model showed the possible occurrence of the species in Guyana and western Colombia, suggesting the need for continued collections of aroids in South America.

We found *P. asplundii* at low altitudes. Other *Philodendron* species also occur in lowland forests, lower mountain ranges, and mid-elevations of higher mountains in the Amazon (**Canal *et al.***, 2019), such as *P. prancei* Croat, which is found in terra firme forests below 150 m.a.s.l. (**Croat *et al.***, 2019). We suggest further investigations to better understand the circumscription of *Philodendron* species from low altitudes in the Amazon and to explore the possibility that *P. asplundii* represents a species complex.

Conclusion

The areas indicated as suitable for the occurrence of *P. asplundii* are located in regions under high risk of forest cover loss due to anthropogenic activities. Furthermore, the new record in this study comes from a permanent preservation area (riparian forest). This points to the need for conservation plans to avoid the loss of suitable habitats of the species, mainly in the Eastern Amazon.

Supplementary information

See the supplementary information in https://www.raccefyn.co/index.php/raccefyn/article/view/3095/4567

Acknowledgments

ALSL thanks the CAPES for the Doctoral scholarship awarded (88887.680100/2022-00). This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001. We thank the Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio, SISBio) for the authorization to collect botanical material for activities with scientific purposes. We also thank Gustavo Reis de Brito, Raimundo Luiz Morais de Sousa, and Weslley Gabriel Cunha Aguiar for their assistance in processing the data, Karena Pimenta for her assistance in the taxonomic identification of the species, and Lisi Alvarenga for revising the English language.

Author contributions

ALSL, **FFVAB** and **MFAS** conceived and designed the study. **ALSL** performed the analyses. **ALSL** and **MFAS** contributed to data acquisition and interpretation. **ALSL** and **FFVAB** wrote the manuscript with the help of **MFAS**. All authors contributed to the discussion, review, and approval of the final manuscript.

Conflicts of interest

The authors declare that they have no conflict of interest.

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