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New records and range extension of a Brazilian Amazon white-sand endemic species: *Roraimaea aurantiaca* Struwe, S.Nilsson & V.A.Albert (Gentianaceae)

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Abstract. *Roraimaea aurantiaca* Struwe, S.Nilsson & V.A.Albert, a white-sand endemic species, was previously known from only two specimens collected in Roraima state, Brazil. Our new field collections and re-identified herbarium specimens expand this species' distribution and include the first records from the Brazilian state of Amazonas. Based on this effort, we present a distribution map, preliminary conservation status of Endangered, the first photographs of living plants, and an updated morphological description. This study aggregates new information on the flora of the northern Amazon Basin, in addition to discussing conservation of *R. aurantiaca*.

Keywords. Amazon Basin, biogeography, campinarana, Helieae, Neotropics, oligotrophic habitat, white-sand ecosystem

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Introduction

Amazonian white-sand ecosystems (i.e., campinaranas) are characterized by predominantly sandy, acidic, and heavily leached soils of very low fertility, and, in some areas, with toxic levels of aluminum (Anderson 1981; Mendonça et al. 2015; Adeney et al. 2016). During the dry season, the campinarana plant community may experience physiological drought since the sandy soils have very low water-retention capacity (Franco and Dezzeo 1994). In contrast, during the rainy season, waterlogging of the root system may occur due to high-water levels, blockage of water drainage by a cemented soil layer (hardpan), or through impermeable rock and clay layers (Kubitzki 1989; Franco and Dezzeo 1994). These conditions function as strong environmental filters that require specific adaptations for plants to thrive under such circumstances, resulting in a highly specialized flora with many endemic species (Anderson 1981; Fine and Baraloto 2016; Guevara et al. 2016; Demarchi et al. 2022).

Several taxa mostly restricted to campinaranas have been described in the last three decades in the Gentianaceae (Struwe et al. 1997; Struwe and Albert 1998,

2004; Molina and Struwe 2008). Worldwide, the family comprises 103 genera and approximately 1,740 species, mostly herbs and shrubs, but also some trees (Struwe 2014; Plants of the World Online 2023). Leaves are simple and opposite or rarely whorled or alternate; inflorescences are usually a dichasium or rarely in racemes or solitary flowers; flowers are white, green, yellow, pink, magenta, purple, or blue, or less commonly red to orange; and fruits are usually dehiscent capsules, or rarely berries or indehiscent capsules, and with nearly always a persistent calyx (Calió et al. 2022). Gentianaceae has many small genera with a large morphological variation with species that occur either on the tabletop mountains (tepuis, also nutrient-poor substrates) of the Guiana Highlands of Brazil, Venezuela, and Guyana, and/or in lowland campinaranas in the Amazon and Orinoco river basins (e.g., *Aripuana* Struwe, Maas & V.A.Albert, *Chelonanthus* Gilg, *Chorisepalum* Gleason & Wodehouse, *Irlbachia* Mart., *Potalia* Aubl., *Roraimaea* Struwe, S.Nilsson & V.A.Albert, *Tachia* Aubl., and *Yanomamua* J.R.Grant, Maas & Struwe).

The genus *Roraimaea* is recognized by its long, yellow-orange, tubular corolla and a deeply divided style with filiform lobes that differentiate it from other gentian genera (Struwe et al. 2008). Molecular-based phylogenetic studies have not yet been carried out on *Roraimaea*, but preliminary placements using morphology on a DNA-based backbone phylogeny of the tribe Helieae have placed *Roraimaea* as sister to *Aripuana*, another long-tubular, white-sand genus (Struwe et al. 2009). *Roraimaea* has a restricted distribution in acidic and water-stressed habitats and is composed of only two herbaceous species, *R. coccinea* (Steyermark ex Struwe, S.Nilsson, & V.A.Albert) Struwe, S.Nilsson & V.A.Albert, which was described in 1998, and *R. aurantiaca* Struwe, S.Nilsson & V.A.Albert, which was described 10 years later in 2008 (Struwe et al. 2008). Both have only been collected twice, the first species on the border between Brazil (Amazonas) and Venezuela in high-altitude areas of Pico da Neblina, and the second species in campinaranas in the state of Roraima in Brazil (Struwe et al. 2008).

Based on field collections and a review of mis- and unidentified specimens in herbaria, we present new records of *R. aurantiaca* that drastically expand its geographic distribution. Additionally, we provide the first field photographs of this species, a preliminary conservation status, and describe previously unknown morphological characteristics seen in fresh material.

Methods

The new collections and observations of *Roraimaea aurantiaca* were made in the Uatumã Sustainable Development Reserve (USDR) as part of the project PELD MAUA (Brazilian Long-term Ecological Research Network; Ecology, monitoring, and sustainable use of wetlands) during 2014–2023. The USDR covers an area of about 4,244 km^2. The reserve is located in northeastern area of Amazonas state, Brazil, in the municipalities of Itapiranga, Presidente Figueiredo, and São Sebastião do Uatumã (02°00′–02°40′S, 058°00′–059°20′W; IDESAM 2009). The USDR has an equatorial pluvial climate with a remarkably seasonal precipitation averaging 2,077 ± 438 mm annually (Sombroek 2001). The dry season lasts from June to October, with August and September driest (monthly average of 72 mm), and the rainy season lasts from November to May, peaking in March and April (monthly averages of 298 and 279 mm, respectively). The annual average temperature of the area is approximately 27 °C (Carneiro and Trancoso 2007). The campinaranas are scattered in the matrix of terra-firme forests and occur as patches in the USDR. These patches range from 80 ha to >1000 ha in area. In total, campinaranas occupy approximately 34,800 ha, corresponding to about 8% of the area of the USDR (Demarchi et al. 2022).

Specimens were collected, georeferenced, and herborized following standard procedures for botanical samples (Fidalgo and Bononi 1989) and deposited in the INPA herbarium (acronym according to Thiers 2023). Colors of living plant parts and ecological information were recorded in the field and gathered from the labels of previously collected specimens. The updated species description is an amended version of the original description (Struwe et al. 2008) and based on information from all herbarium specimens, including the new ones and those previously misidentified in the INPA herbarium. Flower measurements were taken from fresh or rehydrated flowers and floral buds.

To survey all possible records of *R. aurantiaca*, we also checked all herbarium records of the related and morphologically similar genera *Chelonanthus* and *Irlbachia*, as well as all samples filed as "indeterminate Gentianaceae spp." in the IAN, INPA, K, MG, MO, NY, and VEN herbaria (acronyms according to Thiers 2023). We also consulted approximately 200 images of exsiccates of the same taxonomic groups in virtual herbaria available online (Field Museum 2023; Reflora 2023; speciesLink 2023; Tropicos.org 2023). We mapped confirmed species records according to the original geographic coordinates on specimen labels or with inferred coordinates using the geographic information from communities and rivers listed on the labels when coordinates were absent. The map was prepared using QGIS v. 3.24.2 (QGIS Development Team 2021). The preliminary conservation status of the *R. aurantiaca* is discussed based on the IUCN (2012) criteria using Extent of Occurrence (EOO) and Area of Occupancy (AOO), which were calculated using GeoCAT software (Bachman et al. 2011).

Results

***Roraimaea aurantiaca* Struwe, S.Nilsson & V.A.Albert**
Harvard Papers in Botany 13(1): 35–45 (Struwe et al. 2008)

Figures 1, 2

Type. BRAZIL – **Roraima** • São Luiz do Anauã, Estrada

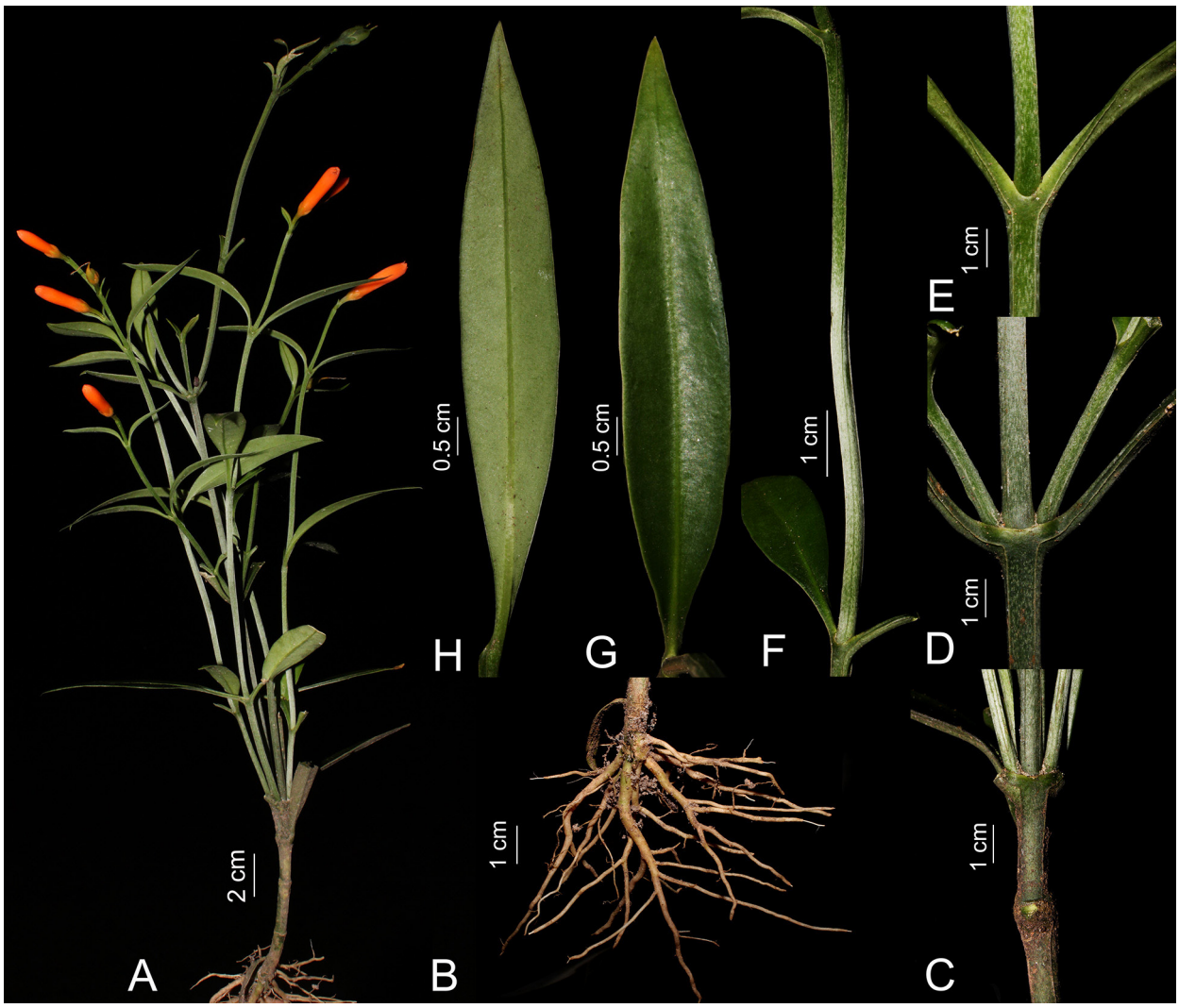

Figure 1. *Roraimaea aurantiaca*. **A.** Habit. **B.** Roots. **C–E.** Branches and nodes from basal to distal portion. **F.** Internode. **G.** Adaxial face of leaf. **H.** Abaxial face of leaf. Photos from L.O. Demarchi 1772, collected in São Sebastião do Uatumã.

Manaus–Caracaraí, BR 174 (km 376), Vicinal da Vila do Equador; 00°10′S, 060°52′W; 23.VIII.1987; C.A. Cid Ferreira 9125 leg.; INPA 153913.

Previously known records. BRAZIL – **Roraima** • São Luiz do Anauã, Estrada Manaus–Caracaraí, BR 174 (km 350); 12.II.1979; W. Rodrigues et al. 10119 leg.; INPA 81681.

New records. BRAZIL – **Amazonas** • São Sebastião do Uatumã, RDS Uatumã, Ramal do projeto ATTO, próximo as parcelas PELD-MAUA; 02°11′01.40″S, 059° 01′09.36″W; alt. 38 m; 08.II.2015; L.O. Demarchi 19 leg.; INPA 287406 • ibid.; 02.VIII.2014; L.O. Demarchi et al. 129 leg.; INPA 268602 • ibid.; 08.II.2022; L.O. Demarchi 1772 leg.; INPA 294931 • ibid.; 16.VIII.2022; L.O. Demarchi 1800 leg.; INPA 294959 • ibid.; 05.XI.2022; L.O. Demarchi 1848 leg.; INPA 295006 • ibid.; 14.II. 2023; L.O. Demarchi 1917 leg.; INPA 296021 • São Sebastião do Uatumã, RDS Uatumã; 02°17′03″S, 059°01′ 43″W; 12.VII.2011; F.M. Costa 1879 leg.; INPA 283005 • Presidente Figueiredo, near the Balbina water reservoir; 01°56′S, 059°28′W; alt. 35 m; 27.XI.2012; J.E. Householder 2331 leg.; INPA 269011 • São Gabriel da Cachoeira, Rio Içana/Rio Negro, near the mouth of Rio Cubate; 00°33′S, 067°38′W; alt. 150 m; 04.XI.1987; P.J.M. Maas et al. 6922 leg.; INPA 158347.

Identification. Branched suffrutescent herb up to 1.5 m tall; branched from base with many flowering stems, without basal vegetative shoots; with white crystalline deposits on leaves and flowers when dry. Roots fibrous, highly branched. Stem and branches 0.3–0.5 cm thick at base of plant, 0.1–0.3 cm thick below inflorescences, terete, with 4 thin, decurrent lines when fresh. Leaves cauline, petiolate or barely so; lamina narrowly ovate to lanceolate, 4.6–6.4 × 0.7–1.5 cm, slightly succulent when fresh, usually thin and papyraceous but not translucent when dry; petiole 0.1–0.7 cm long; base acute to attenuate; apex acute to acuminate; margin thin, membranaceous when dry, flat; venation when fresh barely visible, when dry with 5–12 pairs of inconspicuous secondary veins, diffuse and reticulate tertiary veins. Inflorescence 3–18-flowered; peduncle 1.2–4.4 cm long; pedicel 0.1–0.5 cm long; floral bracts scale-like, narrowly triangular, thin, 0.1–0.2 cm long, sometimes with ciliate margins. Flowers erect or nearly so. Calyx 0.2–0.6 cm long, greenish yellow to orange, divided down

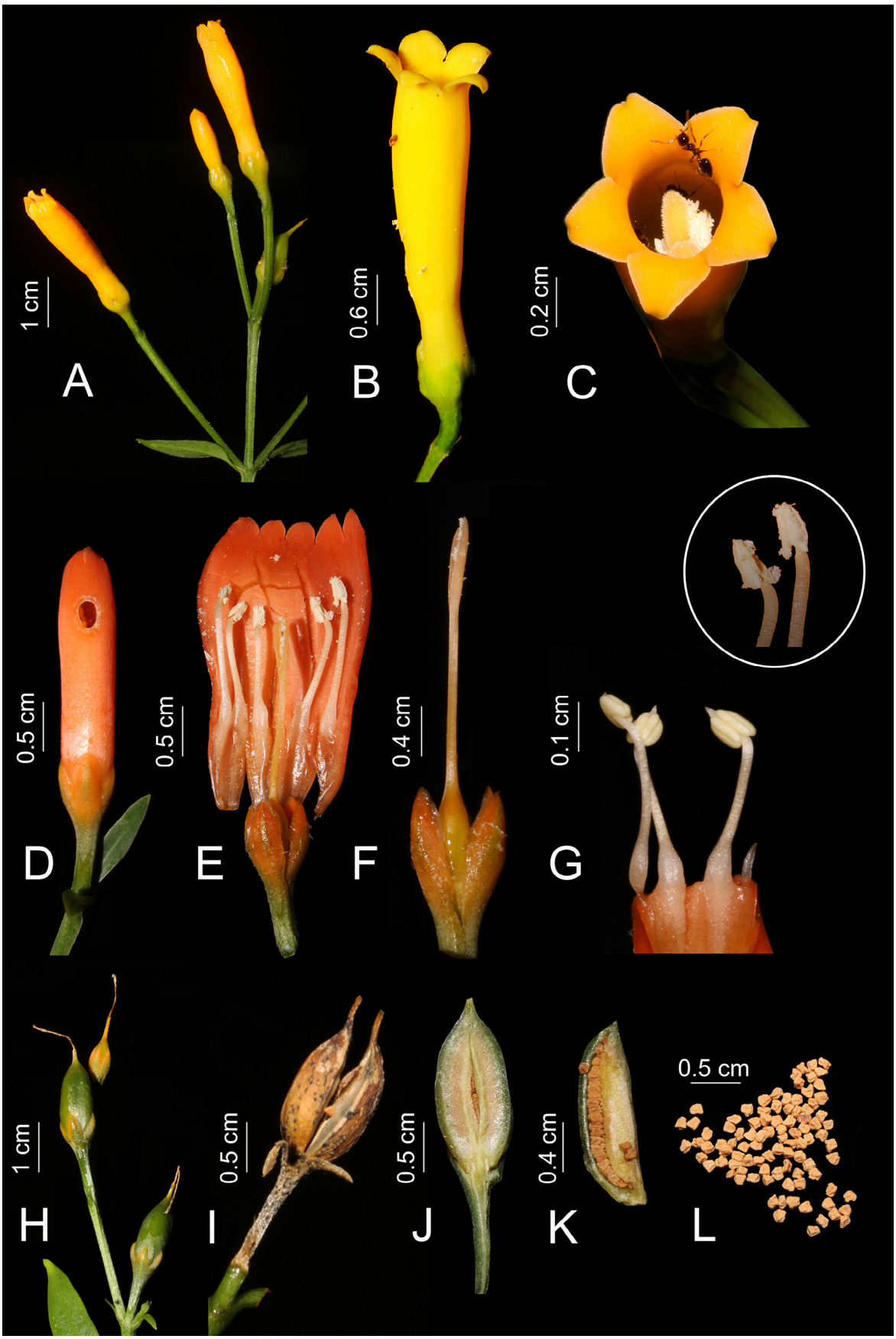

Figure 2. *Roraimaea aurantiaca*. **A–C.** Branch and flowers of the yellow flower type. **D.** Floral bud of the orange flower type pierced by ants. **E.** Open flower showing stamens and gynoecium. **F.** Detail of calyx and gynoecium. **G.** Insertion of stamens in corolla, filaments with thickened bases, basifixed anthers, and detail of anthers at anthesis with pollen grains. **H.** Branches with immature fruits and persistent styles**. I.** Mature, dehisced fruits. **J.** Opened mature fruit, showing placentation and mature seeds**. K.** Detail of opened fruit, showing placentation and position of seeds. **L.** Seeds. Photos A–C from L.O. Demarchi 19, D-H from L.O. Demarchi 1772, I–L from L.O. Demarchi 1800, all of them collected in São Sebastião do Uatumã.

to ½–⅔ of its total length, persistent in fruit; lobes elliptic, obtuse, 0.2–0.3 × 0.2–0.5 cm, with thickened keel. Corolla tubular, 0.8–1.4 cm long at anthesis, deep yellow to dark orange, yellowish brown when dry; tube 2.0–3.5 cm long, 0.2–0.7 cm wide at base, 0.4–1.2 cm wide at mouth; lobes erect to spread at anthesis, elliptic, 0.3–0.5 × 0.4–0.6 cm, thick, papillose, acute; bud apex slightly tapering. Stamens inserted in corolla tube about ⅓ from corolla base; filaments white, terete, strongly thickened at base, 0.3–0.4 cm; anthers white, basifixed, ca. 0.2 × 0.1 cm, with a small sterile acute tip. Gynoecium with a nectariferous disk at the ovary base; ovary 0.7–0.8 cm long; style 0.6–1.6 cm long; stigma lobes 2, narrowly elliptic, 0.2–0.4 cm long; style partially deciduous during fruit development. Capsules green initially, brown when mature and dry, 0.5–1.5 × 0.2–0.7 cm, apically dehiscent; style remnant 0.1–0.2 cm long when dehisced; exocarp dull; placenta fibrous. Seeds many, angular-irregular in shape with sunken areas; seed size 560–810 × 630–915 μm; testa cells polygonal, more elongated along the rims, with convex outer walls, creating a bubbly appearance on surface; outer testa wall with thickened foraminate reticulum with rounded meshes.

Taxonomic notes. Field observations allow us to update the species description, especially the floral characters, as gentian flowers and fruits often shrink up to 10–15% when drying (Struwe et al. 2008). Another important characteristic observed in the field was the color of the flowers; corollas were previously known only as orange, which is unusual in gentians, but the new records also showed yellow flowers, a more common characteristic in the family. *Roraimaea aurantiaca* can be differentiated from other species of Gentianaceae and other genera of the tribe Helieae by deep-yellow or orange flowers and in having long filiform stigma lobes (Struwe et al. 2008). Compared to *R. coccinea*, the only other species of the genus, *R. aurantiaca* is distinguished by its densely branched habit (vs. unbranched or sparsely branched habit in *R. coccinea*), leaves cauline, not in basal rosettes (vs. most leaves in basal rosette or on basal vegetative shoots), inflorescence 3–18-flowered (vs. inflorescence usually with a solitary flower, rarely with two flowers) and tubular corolla (vs. salver-shaped corolla; Struwe et al. 2008; for information on other gentians see Struwe et al. 2009).

Distribution. The searching of additional mis- or unidentified herbarium specimens allowed us to identify five areas of occurrence for *R. aurantiaca*, two already known in southern Roraima state and three in Amazonas state, two of them in the Uatumã river basin and one in the upper Rio Negro basin (Fig. 3). Therefore, the geographical occurrence of *R. aurantiaca* is considerably enlarged, with the two most distant records approximately 1000 km from the original collections.

Habitat. All records of *R. aurantiaca* were in campinaranas. In the USDR, the records were made specifically in two phyto-physiognomies or habitats. In the open shrubby campinarana, the species occurs in open areas, exposed directly to the sunlight, in small islands of vegetation along with other species such as *Humiria balsamifera* var. *guianensis* (Benth.) Cuatrec (Humiriaceae) and *Aldina heterophylla* Spruce ex Benth (Fabaceae). In the open arboreal campinarana, the species occurs in the forest understory where sunlight penetration is high (phyto-physiognomies according to Demarchi et al. 2022).

Phenology. *Roraimaea aurantiaca* has an annual reproduction strategy and was recorded with flowers and fruits in February, July, August, and November.

Conservation status. *Roraimaea aurantiaca* has an estimated extent of occurrence (EOO) of 83,000 km^2, an area of occupancy (AOO) of 20.000 km^2, and only five known locations (B2a) (Fig. 3). Some campinaranas where subpopulations of *R. aurantiaca* were collected (J.E. Householder 2331) have been affected by the construction of the Balbina hydroelectric dam (Schöngart et al. 2021), resulting in the flooding of large areas to form the reservoir for power generation; this development has probably negatively affected the populations of this species (A1c + B2bi, iii). The two locations in southern Roraima state (C.A. Cid Ferreira 9125 and W. Rodrigues et al. 10119) are outside of protected areas, and the region has been progressively suffering from the advance of large oil-palm plantations (*Elaeis guineensis* Jacq.), including campinarana areas, possibly impacting populations of *R. aurantiaca* (A1c + B2bi, iii) (Lonova 2021). So, based on the IUCN (2012) criteria, the species can be classified as Endangered. Campinaranas where the species was collected, and other campinaranas within the EOO polygon, are integrated in protected areas, such as USDR (F.M. Costa 1879, L.O. Demarchi 19, 129, 1772, 1800, 1848 and 1927), the Waimiri-Atroari and Alto Rio Negro Indigenous Reserve (P.J.M. Maas et al. 6922), and the Baixo Rio Branco-Jauaperi Extractive Reserve. The difficulty of accessing some of these regions contributes to their protection.

Discussion

The new records confirm that *Roraimaea aurantiaca* is restricted to campinarana habitats, a fact noted by Struwe et al. (2008) but based on only two records. Although the EOO of this species is large (due to our newly found records), the vast majority of this area is composed of terra-firme forests (see map by Adeney et al. 2016) and habitats in most of this area are likely not suitable for the species. In fact, despite being widespread across the Amazon Basin, campinaranas occupy only about 5% of basin's area (Adeney et al. 2016). Campinaranas occur only as vast and continuous lowland areas in the upper Rio Negro basin, but in other regions of the Amazon these ecosystems occur as islands within a different forest type (Anderson 1981; Prance 1996). The fragmented distribution of campinaranas may contribute to the isolation of populations of many species, especially those

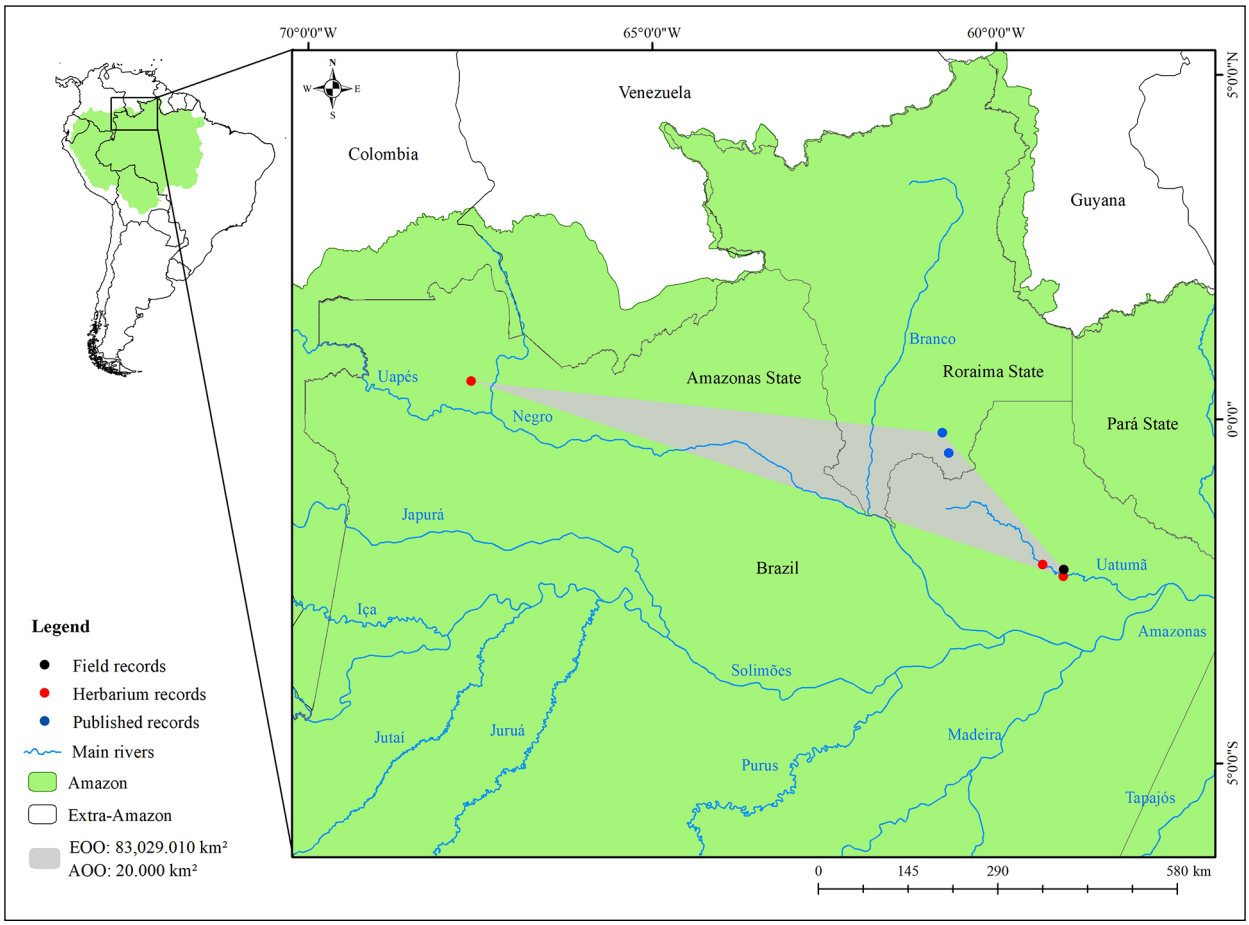

Figure 3. Range extension of *Roraimaea aurantiaca* in the Brazilian Amazon. **Published records** correspond to the known distribution of the species as published by Struwe et al. (2008). **Herbarium records** correspond to misidentified species in herbaria found in our review. **Field records** correspond to new field records and those used to illustrate this article. **EOO** represent Extent of Occurrence. **AOO** represent Area of Occupancy calculated in GeoCAT software.

with limited dispersal strategies (Macedo and Prance 1978).

In recent decades, several campinarana have been threatened by activities such as selective logging (Demarchi et al. 2019), burning (Hammond and ter Steege 1998; Adeney et al. 2016; Costa et al. 2023), and extraction of sand for construction, mainly near urban centers (Ferreira et al. 2013). This makes it essential to develop specific conservation strategies for these special ecosystems, since vast and continuous campinaranas that are potential localities for *R. aurantiaca* are not integrated in protected areas. The lack of records of *R. aurantiaca* from other regions containing campinarana ecosystems may be linked to the fact that almost all campinarana inventories and floristic studies have been concentrated in just a few areas, usually close to cities and research centers, while large sampling gaps exist in many remote locations (Hopkins 2007, 2019). Although we provide new and important information on the distribution and conservation of *R. aurantiaca*, much ecological information, population status, and specific threats are still unknown. So, we emphasize the need to study these environments more thoroughly.

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