RESEARCH ARTICLE

Brazilian Flora 2020: Leveraging the power of a collaborative scientific network

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Abstract The shortage of reliable primary taxonomic data limits the description of biological taxa and the understanding of biodiversity patterns and processes, complicating biogeographical, ecological, and evolutionary studies. This deficit creates a significant taxonomic impediment to biodiversity research and conservation planning. The taxonomic impediment and the biodiversity crisis are widely recognized, highlighting the urgent need for reliable taxonomic data. Over the past decade, numerous countries worldwide have devoted considerable effort to Target 1 of the Global Strategy for Plant Conservation (GSPC), which called for the preparation of a working list of all known plant species by 2010 and an online world Flora by 2020. Brazil is a megadiverse country, home to more of the world's known plant species than any other country. Despite that, *Flora Brasiliensis*, concluded in 1906, was the last

comprehensive treatment of the Brazilian flora. The lack of accurate estimates of the number of species of algae, fungi, and plants occurring in Brazil contributes to the prevailing taxonomic impediment and delays progress towards the GSPC targets. Over the past 12 years, a legion of taxonomists motivated to meet Target 1 of the GSPC, worked together to gather and integrate knowledge on the algal, plant, and fungal diversity of Brazil. Overall, a team of about 980 taxonomists joined efforts in a highly collaborative project that used cybertaxonomy to prepare an updated Flora of Brazil, showing the power of scientific collaboration to reach ambitious goals. This paper presents an overview of the Brazilian Flora 2020 and provides taxonomic and spatial updates on the algae, fungi, and plants found in one of the world's most biodiverse countries. We further identify collection gaps and summarize future goals that extend beyond 2020. Our results show that Brazil is home to 46,975 native species of algae, fungi, and plants, of which 19,669 are endemic to the country. The data compiled to date suggests that the Atlantic Rainforest might be the most diverse Brazilian domain for all plant groups except gymnosperms, which are most diverse in the Amazon. However, scientific knowledge of Brazilian diversity is still unequally distributed, with the Atlantic Rainforest and the Cerrado being the most intensively sampled and studied biomes in the country. In times of "scientific reductionism", with botanical and mycological sciences suffering pervasive depreciation in recent decades, the first online Flora of Brazil 2020 significantly enhanced the quality and quantity of taxonomic data available for algae, fungi, and plants from Brazil. This project also made all the information freely available online, providing a firm foundation for future research and for the management, conservation, and sustainable use of the Brazilian funga and flora.

Keywords big data; biodiversity; natural history collections; repositories; South America; taxonomic impediment

Supporting Information may be found online in the Supporting Information section at the end of the article.

■ INTRODUCTION

Despite the massive availability of biodiversity data, with ~10^9 digital records available online documenting species occurrences in space and time (see Robertson & al., 2014; Anderson & al., 2020), many misidentified specimens remain in our physical collections and online databases. Indeed, some estimates indicate that more than half of tropical plant specimens are misidentified or have identifications that require updating (Goodwin & al., 2015). The shortage of reliable primary taxonomic data limits the description of biological taxa, patterns, and processes, producing a chain of misconceptions (see examples in Lagomarsino & Frost, 2020) in biogeographical, ecological, and evolutionary research (de Oliveira & al., 2020). This deficit also creates significant impediments to biodiversity research, to the establishment of conservation strategies (Hortal & al., 2015; Anderson & al., 2020), and to potential biodiversity uses. The taxonomic impediment, plant blindness, and the biodiversity crisis have been recognized as serious issues in the last decade (Ebach & al., 2011; Sluys, 2013; Crisci & al., 2020; Lagomarsino & Frost, 2020). Two distinct but interlinked phenomena are confounded in the taxonomic impediment (Ebach & al., 2011). The first concerns the lack of reliable taxonomic information available to "consumers", while the second encompasses the myriad of difficulties faced by taxonomists due to insufficient financial resources for research and the low impact factors of taxonomic publications (Ebach & al., 2011; Lester & al., 2014; Crisci & al., 2020). These two phenomena prevent the scientific community from describing and studying biodiversity in a timely fashion, causing many species to go extinct before being documented (Singh, 2002; Cheek & al., 2020; Raven & Miller, 2020). Without accurate names and reliable information about the morphology, distribution, phenology, and phylogenetic relationships among taxa, the management, conservation, and use of biodiversity are seriously compromised. Studies focusing on describing and understanding biodiversity should be the main priority in the biological sciences in the decades to come (Grace & al., 2021).

Although the exact number of species on Earth remains to be determined, it is estimated that there are around 8.7 million eukaryotic species names, referring to an estimated 1.2–1.8 million accepted species (Mora & al., 2011). This diversity includes approximately 44,000 algae, 9,000 liverworts, 225 hornworts, 12,700 mosses, 1,290 lycophytes, 10,560 ferns, 1,079 gymnosperms (Christenhusz & Byng, 2016), and c. 370,000 species of angiosperms, although these numbers are sensitive to the method and dataset used (Nic Lughadha & al., 2017; Cheek & al., 2020). The Neotropical region is the most species-rich area in the world (Antonelli & Sanmartin, 2011; Lagomarsino & Frost, 2020; Raven & Miller, 2020; Raven & al., 2020), encompassing at least six biodiversity hotspots (Mittermeier & al., 2011). Brazil, the largest country in South America, houses one of the largest numbers of vascular plant species in the world (Giulietti & al., 2005). However, the number of plants occurring in Brazil remained uncertain throughout the 20th century, with the lack of confident data ending only at the beginning of the 21st century (Forzza & al., 2010a).

The most comprehensive work to reliably document Brazilian plant diversity was, until recently, *Flora Brasiliensis* edited by Martius (1840–1906). The history of this encyclopedic work started more than 200 years ago, with the great expedition conducted by Carl Friedrich von Martius and Johann Baptist von Spix (1817–1820) to the main phytogeographic domains of Brazil. *Flora Brasiliensis* documented 22,767 species in total, of which 19,629 were reported to occur in Brazil, while the remaining 3,138 species were found in neighbouring countries. Martius & al. (1833) described 80 algae, 177 lichens and 79 liverworts and anthoceros. When the editors Martius, and, later, August W. Eichler and Ignatz Urban finalized the 15 volumes and 140 parts that constitute

the *Flora Brasiliensis* (Urban, 1906), they probably did not imagine that a full description of Brazil's extant biodiversity would still await completion more than a century later.

Through the 20th century and the first decades of the new millennium, numerous field expeditions and herbarium-based taxonomic studies resulted in thousands of newly described species. At the same time, many published species names were relegated to synonymy. Due to this large volume of data and taxonomic changes, providing an accurate estimate of the number of known algae, fungi, and plant species from Brazil became an increasingly complex task. Although several authors tried to estimate the angiosperm diversity of Brazil, with numbers ranging from 36,000 to more than 60,000 angiosperm species (e.g., MMA, 1998; Govaerts, 2001; Lewinsohn & Prado, 2002; Giulietti & al., 2005; Shepherd, 2005), these estimates were based on extrapolations from incomplete datasets and no reliable assessments based on a detailed checklist were undertaken in the century following the completion of *Flora Brasiliensis*.

■ THE BRAZIL FLORA 2020 AND RELATED PROJECTS

In response to the GSPC, adopted by the Parties to the Convention on Biological Diversity (UNEP, 2002: COP Decision VI/9), Brazil committed to produce a comprehensive list of all algae, fungi, and plants occurring in the country by 2010 (GSPC Target 1). Through a project initiated in 2008, botanists achieved Target 1 in 2010 with the publication of the online "List of the Species of the Brazilian Flora" ("Lista de Espécies da Flora do Brasil") and the "Catalogue of Brazilian Plants and Fungi" ("Catálogo de Plantas e Fungos do Brasil"). This publication documented 40,989 species of algae, fungi, and plants, representing the most accurate estimate of Brazilian plant diversity for a century (Forzza & al., 2010a). This work confirmed earlier expectations that Brazil is the country with the largest number of known vascular plant species in the world (Forzza & al., 2010b, 2012).

Accessing and cataloguing the diversity of a megadiverse country such as Brazil requires not only the collaborative work of well-trained taxonomists around the world, but also the development of tools for rapid and efficient data sharing, including the analysis of specimens deposited in herbaria worldwide. To speed up the completion of the first species list, an online information system was developed, enabling the collaboration of researchers based in many different countries and the workflow to achieve GSPC Target 1 (i.e., a freely available list of all known plants and fungi), the first step towards meeting the other GSPC targets ranging from species conservation assessments to *in* and *ex situ* conservation actions (Paton & al., 2008). The online system also facilitated the ongoing refinement of the list, adding new records and newly described taxa, as well as information on species habit, substrate, and vegetation types. From 2010 to 2015, the list was updated by more than 430 specialists, reaching total species counts of 4,747 algae (Menezes & al., 2015); 5,719 fungi (Maia & al., 2015); 1,524 bryophytes (Costa & Peralta, 2015); 1,253 ferns and lycophytes (Prado & al., 2015); 32,086 angiosperms; and 23 gymnosperms occurring in Brazil (BFG, 2015).

From 2016 to 2020, an additional 554 taxonomists joined the team in a second project, entitled "Brazilian Flora 2020 (BF 2020)". This ambitious and innovative project aimed not only to prepare an updated species list, but also to add detailed and standardized morphological descriptions, illustrations, nomenclatural data, geographic distribution, and keys for the identification of all taxa included in the online system. In 2018, the first report of the BF2020 project was published, documenting 4,754 algae, 5,718 fungi, 1,568 bryophytes, 1,330 ferns and lycophytes, 30 gymnosperms, and 33,099 angiosperms, summing to a total of c. 46,000 species (BFG, 2018).

Each herbarium or fungarium specimen represents auditable evidence of an organism's past geographical distribution (Paton & al., 2020). Thus, specimens in herbaria and fungaria are authoritative records of biodiversity, being vitally important for the information they embody and providing the basis for taxonomic, spatial, and temporal research (Funk, 2018; Bakker & al., 2020; Crisci & al., 2020; Paton & al., 2020). Extensive specimen digitization of natural history specimen collections is transforming taxonomic studies into "big data science" (Hortal & al., 2015; Miralles & al., 2020), highlighting the importance of e-infrastructure for biodiversity studies, especially for megadiverse countries (Canhos & al., 2015). Initiatives of this nature are crucial for the delivery of the 2020 GSPC Targets.

Late in 2010, a project entitled "Plants of Brazil: Historic Rescue and a Virtual Herbarium for Knowledge and Conservation of the Brazilian Flora – Reflora" ("Plantas do Brasil: Resgate Histórico e Herbário Virtual para o Conhecimento e Conservação da Flora Brasileira – Reflora") was developed to complement ongoing efforts to produce a revised Flora of Brazil. This project aimed to build a virtual herbarium to host repatriated high-resolution images of Brazilian plants deposited in herbaria around the world, focusing initially on specimens housed at K, P and RB (Thiers, 2014). By 2013, the Reflora project was integrated into the Brazilian Flora 2020 online system and it progressed rapidly from 2014 to 2020, with the support of two additional projects that also aimed to contribute to the digitization of Brazilian biodiversity data: "The Brazilian Biodiversity Information System" ("Sistema de Informação sobre a Biodiversidade Brasileira", SiBBr, http://www.sibbr.gov.br) and the "National Forest Inventory" ("Inventário Florestal Nacional", IFN, http://ifn.florestal.gov.br). These initiatives allowed the incorporation of data and images from other national and foreign herbaria into the online platform, including specimens deposited at numerous Brazilian herbaria (see http://reflora.jbrj.gov.br/reflora/herbarioVirtual/) (BFG, 2018).

The system implemented in Reflora allowed not only the visualization of high-resolution images, but also the curation of specimens and records through the addition of updated taxonomic identifications, contributing directly to the preparation

of monographs for each major group of Brazilian algae, plant, and fungal species. The searchable online metadata allows researchers to easily access millions of specimens through the Reflora Virtual Herbarium, significantly contributing to plant research while providing an evidence-base for the appropriate management and conservation of plants (Funk, 2018; Bakker & al., 2020; Paton & al., 2020). In 2008, a project entitled "National Institute of Science and Technology (INCT): Virtual Herbarium of Flora and Fungi" (Maia & al., 2015, 2017), was launched aiming to increase the number of images of plants and fungi from national and international herbaria available online (see http://inct.florabrasil.net).

The power of scientific collaboration, along with the mutual goal of reaching GSPC Target 1, was the driving force responsible for uniting a legion of taxonomists to undertake the six projects briefly described above, all focused on documenting and increasing knowledge of algae, plant, and fungal diversity of Brazil. As a contribution to the era of cybertaxonomy and to overcome the taxonomic impediments, here we present an overview of the BF2020 and Reflora projects, highlighting the taxonomic and spatial updates of Brazilian plant, algal, and fungal data that were necessary to meet the GSPC targets. We further identify major gaps and shortcomings of the BF2020 and present future goals that are crucial for the continuous documentation, understanding, and sustainable use of Brazil's exceptional diversity of algae, fungi, and plants.

The long trajectory of the BF2020 project, from 2008 to 2020, highlights the importance of collaborative efforts among taxonomists towards achieving a common goal. Through the collaboration and hard work of this vast network of researchers, the BF2020 project achieved the Target 1 established by the GSPC-CBD for 2020, making a comprehensive online system about the Brazilian flora freely available online. The databases that grew as part of these integrated projects provide high-quality and well-curated taxonomic, distribution, and geographic data on the Brazilian Flora, establishing the basis for Target 2 of the GSPC, which entails the preparation of a detailed assessment of the conservation status of all known Brazilian plant species to help guide conservation actions (https://www.cbd.int/gspc/targets.shtml). Furthermore, the results from the BF2020 project contribute data to a broader initiative, the World Flora Online project (http://www.worldfloraonline.org; Borsch & al., 2020).

■ BRAZILIAN FLORA 2020: AN UPDATED ACCOUNT OF ALGAE, FUNGI, AND PLANTS

When the Brazilian Flora 2020 online system closed on 31 December 2020, 138,241 names of species- and infraspecific-level taxa of algae, fungi, and plants had been incorporated into the system (http://floradobrasil.jbrj.gov.br). The 58,339 names added into the system represent an increase of more than 70% since the 2010 online system closed (Forzza & al., 2010a). Overall, 99% of these names were checked by taxonomists, to ascertain whether they represent an accepted species name, a synonym, or an invalid name.

In total, 535 families (or classes for algae and orders for fungi), 5,798 genera, and 46,975 native species of algae, fungi, and plants were recorded in the BF2020, including 19,669 species that are endemic to Brazil (Table 1). For each of these taxa, the online system provides information on nomenclature, geographic distribution (i.e., species endemism and ranges within Brazil, phytogeographic domains, and vegetation types), morphology (including life forms and substrate for species and infraspecific taxa), identification keys, illustrations, and photographs.

The total number of species reported is now 22% greater than in 2010 (Forzza & al., 2010b). The overall growth was heterogeneous among groups though, with the number of known fungal species increasing much more than those for other groups. Specifically, the number of known fungal species increased by 75% from 2010 to 2020, resulting in a total of 6,320 species. Despite that, the number of fungal species included still falls far short of the c. 13,000 species of fungi known to occur in Brazil or ~200,000 undescribed species of fungi estimated to occur in the country (Lewinsohn & Prado, 2002). Contrasting with fungi, growth in the number of angiosperm species documented between 2010 and 2020

Table 1. Total number of native and endemic species of algae, fungi, and plants found in Brazil according to Forzza & al. (2010b) and the Brazilian Flora 2020 system.

Group	Species total 2010	Native endemic species 2010	Species total 2020	Native species total 2020	Native endemic species 2020
Algae	3,496	–	4,993	4,972	–
Fungi	3,608	–	6,320	6,320	–
Bryophytes	1,521	275	1,610	1,584	356
Ferns and lycophytes	1,176	450	1,403	1,380	527
Gymnosperms	26	2	114	23	3
Angiosperms	31,162	17,630	35,549	32,696	18,783
Total	40,989	18,357	49,989	46,975	19,669

The columns "Species Total" include native plus naturalized and cultivated species.

was only 14%, while the increase in endemic species of angiosperm was 7%, representing a net increase of 1,153 species. Given that over 200 plant species new to science are described from Brazil each year (Cheek & al., 2020) and that most newly described species are endemic to the country, the increase in the total number of endemics documented in the Flora of Brazil 2020 was surprisingly low. This slow net increase in numbers of endemic angiosperms is likely due to increased taxonomic understanding and/or geographic data causing species previously considered endemic to be relegated to synonymy and/or recognized to occur beyond Brazil's borders and no longer considered endemic.

Brazil is home to the following native taxa (excluding naturalized or cultivated species):

- Fungi: 14 divisions, 117 orders, 1,437 genera, 6,320 species, and 140 infraspecific taxa;
- Algae: 30 classes, 1,071 genera, 4,972 species, and 1,447 infraspecific taxa;
- Bryophytes: 111 families, 404 genera, 1,584 species, and 76 infraspecific taxa, including 356 endemic species;
- Ferns and lycophytes: 40 families, 156 genera, 1,380 species, and 56 infraspecific taxa, including 527 endemic species;
- Gymnosperms: 5 families, 7 genera, and 23 species, including 3 endemic species;
- Angiosperms: 232 families, 2,723 genera, 32,696 species, and 2,431 infraspecific taxa, including 18,783 endemic species.

Currently, 49,989 species are recognized for the Brazilian funga and flora (including native, cultivated, and naturalized), being 6,320 of fungi, 4,993 of algae, 1,610 of bryophytes, 1,403 of ferns and lycophytes, 114 of gymnosperms, and 35,549 of angiosperms.

Despite the significant loss of native vegetation from the Brazilian Atlantic Rainforest, this region stands out as the most diverse phytogeographic domain for all plant groups studied here, except for gymnosperms, which are most diverse in Amazonia (Table 2). However, knowledge of diversity in Brazil is highly uneven, the Atlantic Rainforest and the Cerrado being much more densely sampled than the Amazon, Caatinga, Pantanal, and Pampa (Antonelli & al., 2018; Stropp & al., 2020). For instance, recent studies have shown that about 50% of the Amazon is undersampled (see Costa & al., 2020; Stropp & al., 2020; Gomes-da-Silva & Forzza, 2021). The Amazon flora is also underrepresented in herbaria (Paton & al., 2020), highlighting the great need for improved collection efforts in this phytogeographic domain. The Pampa stood out as the domain for which the highest number of angiosperms and ferns plus lycophyte records were added to the BF2020 between 2015 and 2020 (see Table 2). On the other hand, updates led to a decrease in the number of confirmed records for some taxa, such as the bryophytes from the Pantanal (Table 2). The Brazilian Atlantic Rainforest and the Cerrado, the two best-studied domains, have shown a small net reduction in numbers of known species since 2015, suggesting that synonymizations and removal of erroneous records outnumbered the new discoveries in these regions. Despite this, we must emphasize that these two biomes are not fully explored and known from a botanical point of view.

The states of Bahia, Minas Gerais, Rio de Janeiro, and São Paulo are the most diverse for various taxonomic groups (see Figs. 1 and 2). In terms of known fungal species richness, São Paulo is the most diverse state (1,900 spp.), followed by Pernambuco (1,651 spp.), and Rio Grande do Sul (1,461 spp.) (Fig. 1). Given that these three states concentrated the greatest number of mycologists in the country, this ranking likely reflects

Table 2. Taxonomic richness of native land plants recorded in the Brazilian phytogeographic domains, based on the BFG (2015), BFG (2018), and Brazilian Flora 2020 project.

		Phytogeographic domain					
Group	BFG	Amazon Rainforest	Atlantic Rainforest	Caatinga	Cerrado	Pampa	Pantanal
Bryophytes	2015	570	1,337	96	478	120	176
	2018	567	1,324	104	472	117	160
	2020	568	1,316	125	483	120	149
Ferns and lycophytes	2015	503	883	26	269	8	30
	2018	525	909	35	272	15	38
	2020	569	926	55	314	116	62
Gymnosperms	2015	16	3	2	6	2	0
	2018	16	10	2	9	2	0
	2020	16	3	2	7	3	1
Angiosperms	2015	11,896	15,001	4,657	12,097	1,685	1,277
	2018	11,846	15,179	4,702	12,113	1,816	1,299
	2020	11,903	14,905	4,781	12,025	2,578	1,470
Total 2020	**Domain**	**13,056**	**17,150**	**4,963**	**12,829**	**2,817**	**1,682**

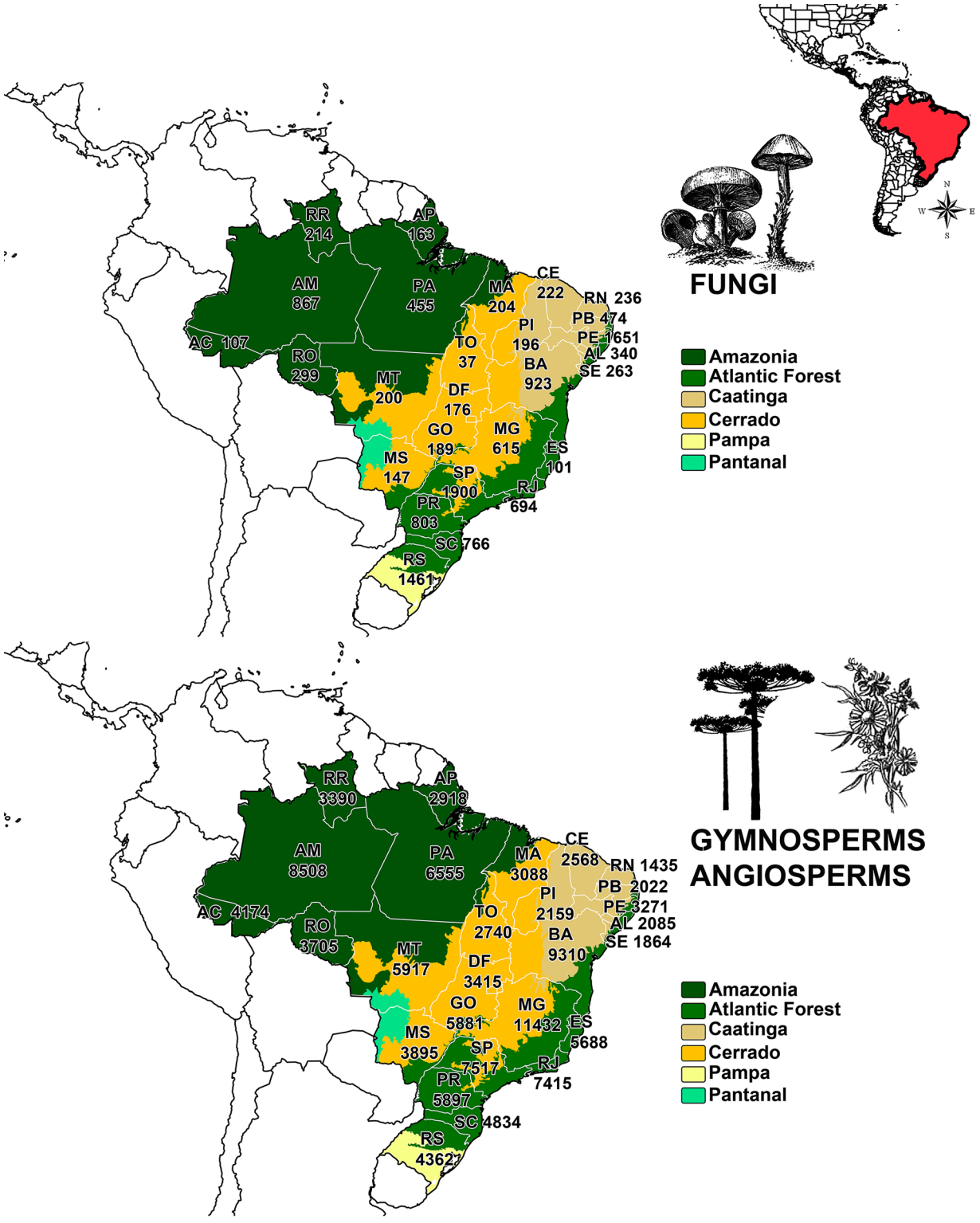

Fig. 1. Number of native species of fungi, and of gymnosperms and angiosperms (collectively termed seed plants) recorded from the states and Federal District of Brazil. The states of São Paulo, Pernambuco, and Rio Grande do Sul have the greatest numbers of fungal species recorded, which may reflect the distribution of mycological expertise rather than fungal diversity. The states of Minas Gerais, Bahia, and Amazonas have the greatest numbers of seed plant species recorded, the total for Amazonia being widely recognized as an underestimate due to undersampling. Acronyms for Brazilian states: AC, Acre; AL, Alagoas; AP, Amapá; AM, Amazonas; BA, Bahia; CE, Ceará; DF, Distrito Federal; ES, Espírito Santo; GO, Goiás; MA, Maranhão; MG, Minas Gerais; MS, Mato Grosso do Sul; MT, Mato Grosso; PA, Pará; PB, Paraíba; PE, Pernambuco; PI, Piauí; PR, Paraná; RJ, Rio de Janeiro; RN, Rio Grande do Norte; RO, Rondônia; RR, Roraima; RS, Rio Grande do Sul; SC, Santa Catarina; SE, Sergipe; SP, São Paulo; TO, Tocantins.

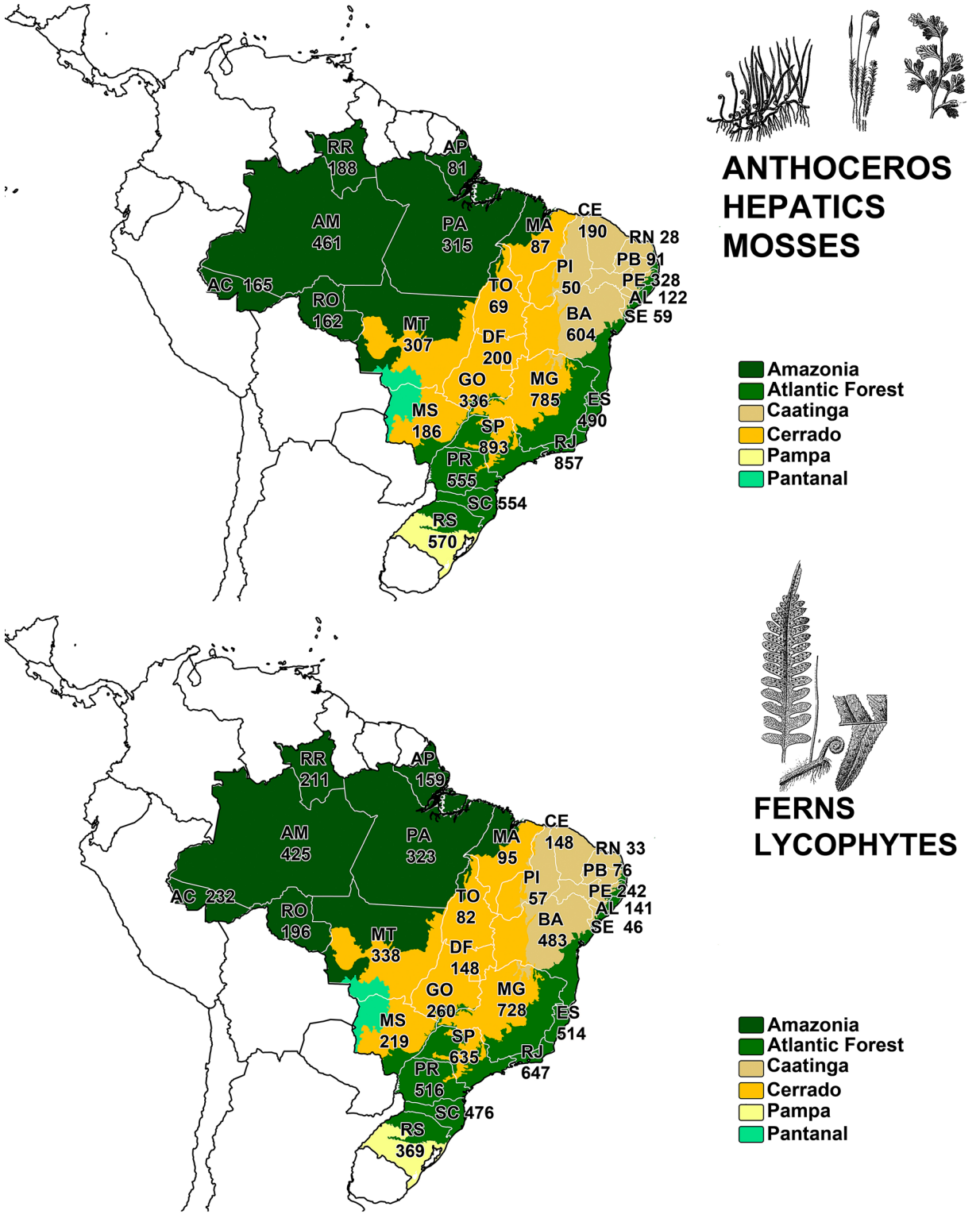

Fig. 2. Number of native species of anthoceros, hepatics, mosses (collectively termed bryophytes) and ferns and lycophytes recorded from the states and Federal District of Brazil. The states of São Paulo, Rio de Janeiro, and Minas Gerais have the greatest numbers of bryophyte species recorded. The states of Minas Gerais, Rio de Janeiro, and São Paulo have the greatest numbers of ferns and lycophytes recorded. Acronyms for Brazilian states: AC, Acre; AL, Alagoas; AP, Amapá; AM, Amazonas; BA, Bahia; CE, Ceará; DF, Distrito Federal; ES, Espírito Santo; GO, Goiás; MA, Maranhão; MG, Minas Gerais; MS, Mato Grosso do Sul; MT, Mato Grosso; PA, Pará; PB, Paraíba; PE, Pernambuco; PI, Piauí; PR, Paraná; RJ, Rio de Janeiro; RN, Rio Grande do Norte; RO, Rondônia; RR, Roraima; RS, Rio Grande do Sul; SC, Santa Catarina; SE, Sergipe; SP, São Paulo; TO, Tocantins.

the distribution of mycologists rather than actual fungal richness patterns in Brazil. For seed plants (Fig. 1), the states with the greatest recorded diversity are Minas Gerais (11,432 spp.) and Bahia (9,310 spp.). For hornworts, hepatics, and mosses (Fig. 2), the states of São Paulo (893 spp.), Rio de Janeiro (857 spp.), and Minas Gerais (785 spp.) house the greatest species diversity. For ferns and lycophytes, Minas Gerais (728 spp.), Rio de Janeiro (647 spp.), and São Paulo (635 spp.) are the most diverse states in the country (Fig. 2).

The top 10 richest angiosperm families in Brazil are Fabaceae (3,033 species), Orchidaceae (2,692), Asteraceae (2,205), Poaceae (1,551), Melastomataceae (1,436), Rubiaceae (1,415), Bromeliaceae (1,379), Myrtaceae (1,193), Euphorbiaceae (973), and Malvaceae (840), together encompassing 16,717 species (Table 3). Although these 10 families represent only 4.3% of the total number of angiosperm families in Brazil, they comprise 51.1% of all angiosperm species diversity recorded in the country. In total, these 10 families encompass more than 9,500 of the species endemic to Brazil (Table 3), representing 57.3% of all species reported for these families in the country. During the five years of the BF2020 project, morphological descriptions were included in the system for more than 3,204 genera and 375 families, comprising all the ferns and lycophytes, bryophytes, and gymnosperms that are native to or naturalized in Brazil. For angiosperms, 90% of the families and 92% of the genera were described morphologically.

With more than 3 billion biological specimens deposited in natural history collections worldwide, many already digitized, there is no doubt that we are in the era of big data and cyberspecimens (see Miralles & al., 2020). The Reflora and INCT-Virtual Herbarium projects enabled the inclusion of specimens from multiple collections and made available millions of occurrence records and high-resolution images of specimens, providing an invaluable foundation for the documentation of species within the BF2020 project. The availability of specimens online became even more important in 2020, when taxonomists faced many constraints to access to the physical collections due to the coronavirus pandemic.

Table 3. Top 10 angiosperm families with the greatest species richness in Brazil, showing their total numbers of native and endemic species, based on the BFG (2015) and the Brazilian Flora 2020.

Families	Native species 2015	Endemic species 2015	Native species 2020	Endemic species 2020
Fabaceae	2,756	1,507	3,033	1,576
Orchidaceae	2,548	1,636	2,692	1,490
Asteraceae	2,013	1,317	2,205	1,361
Rubiaceae	1,375	726	1,415	707
Melastomataceae	1,367	894	1,436	929
Bromeliaceae	1,343	1,174	1,379	1,177
Poaceae	1,281	498	1,551	510
Myrtaceae	1,030	797	1,193	783
Euphorbiaceae	934	638	973	602
Malvaceae	757	406	840	444
Total	15,404	9,593	16,717	9,579

The considerable growth in the number of herbaria represented within the online system illustrates one of the successes of the Reflora project. Reflora started with images from the K, P and RB herbaria (BFG, 2018), but expanded into 86 herbaria representing 7 European, 7 North American, and 72 Brazilian herbaria (see http://reflora.jbrj.gov.br/reflora/herbarioVirtual/). During the eight years of the project (i.e., 2010–2018), three million high-resolution images of botanical specimens were incorporated into the online system (BFG, 2018). Subsequently, over 800,000 digital images of specimens were made available, totalling 3,808,263 digital specimens of the Brazilian flora in the Reflora Virtual Herbarium, including images of 149,186 nomenclatural types. In addition, the INCT-Virtual Herbarium provides digital access to more than 10 million specimens and 4.5 million additional digitized images from 135 Brazilian and 20 foreign herbaria. Today, the Reflora and INCT-Virtual Herbarium together house c. 8 million images.

Despite a continuing decline in plant collecting activities, most notably since 2008, influenced mainly by successive budget cuts of funding agencies in the country, Brazil ranks first in the number of newly described species of plants per year (Antonelli & al., 2020; Cheek & al., 2020). In 2019, 34% of the newly described plant species and 9.5% of the newly described species of fungi worldwide were from South America (Antonelli & al., 2020; Cheek & al., 2020). For Brazil alone, c. 180 new species of algae, 1,500 species of angiosperms (Fig. 3), and 420 new fungi were described between 2015 and 2020. Unfortunately, however, many of the newly described species have small ranges and are already threatened (Cheek & al., 2020). Like many plant species around the world, these taxa may be moving towards extinction (Nic Lughadha & al., 2020). Indeed, at least one in five plant species worldwide (Brummitt & al., 2015; Smith & al., 2017) or even two in five species (Nic Lughadha & al., 2020) may be threatened with extinction. By August 2021, 7,830 of Brazil's 34,099 vascular plant species had been assessed for their extinction risk by Brazil's National Centre for Plant Conservation (Centro Nacional de Conservação da Flora, CNCFlora). Of those assessed, 3,213 were evaluated as threatened (T. Laque/E.P. Fernandez, pers. comm. August 2021). However, the proportion of those assessed that are threatened species (41%) should not be extrapolated to Brazil's flora as a whole because CNCFlora's assessment work has focused on endemic species, including those that had previously been assessed as threatened (all reassessed for Martinelli & Moraes, 2013) and those confined to certain species-rich areas of Brazil (e.g., Rio de Janeiro State).

In 2020, plant diversity in Brazil suffered unprecedented extinction risk, due to countless illegal fires all over the country, especially in the Amazon, Pantanal, and Cerrado, exacerbating the increasing deforestation rates (see INPE, 2020). In addition, Brazil's freshwater, coastal, and marine ecosystems have undergone alarming eutrophication due to climate change and water

pollution, leading to severe species losses (Gilbert, 2020; Jones & al., 2020). However, few studies in Brazil evaluated the threat or loss of algal biodiversity in aquatic ecosystems (see Azevedo-Santos & al., 2019). Research on how eutrophication and climate change influence the many species of algae is urgently needed.

■ GAPS AND FUTURE GOALS BEYOND 2020

Even though the 16 ambitious targets of the GSPC are still far from being met at a global scale (e.g., Sharrock, 2020), most countries have made considerable advances towards their completion. Although much progress has been made

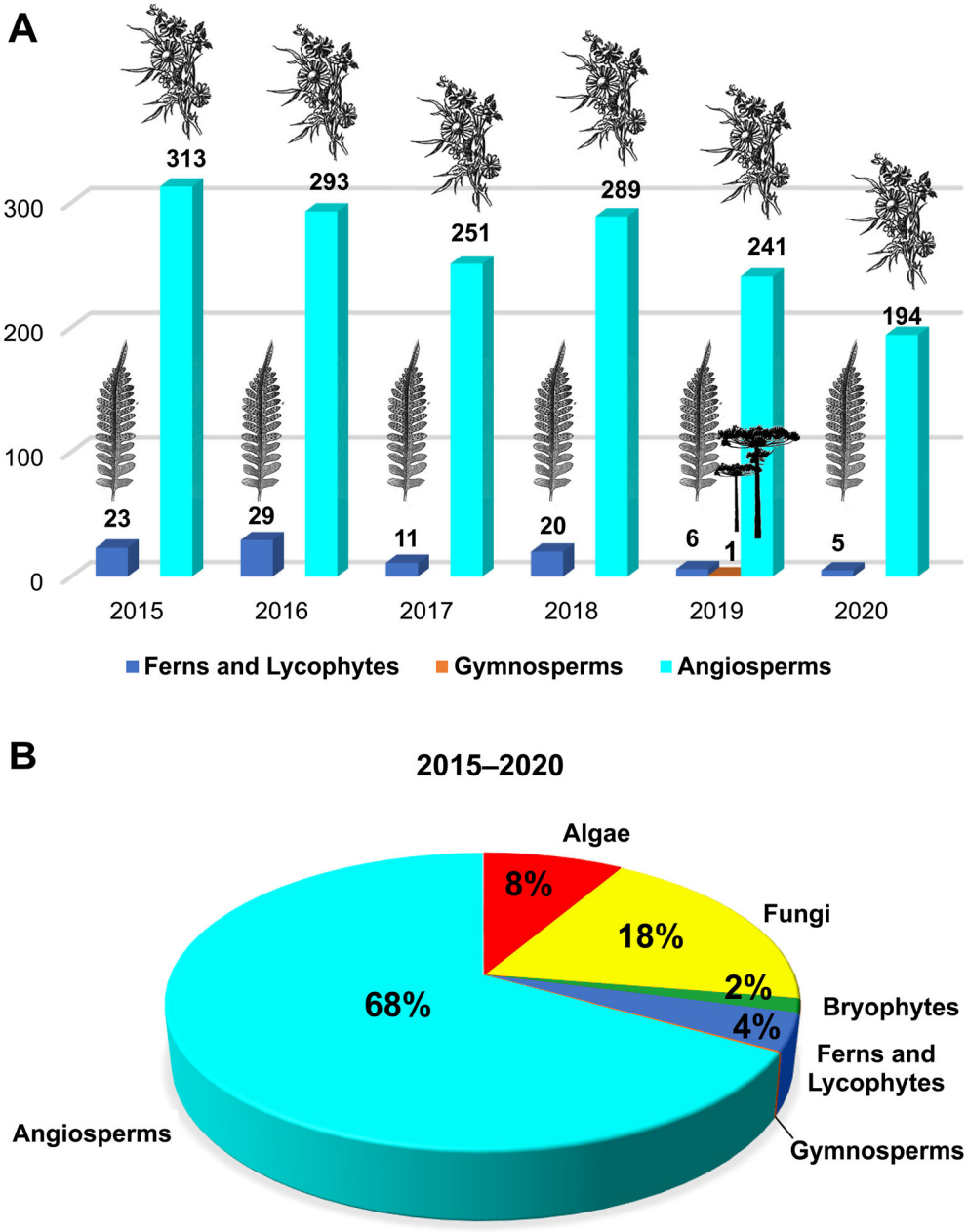

Fig. 3. Percentage and numbers of new species of major plant and fungal taxa described between 2015 and 2020 from Brazil. **A**, Numbers of Brazilian ferns and lycophytes, gymnosperms, and angiosperms described as new to science per year between 2015 and 2020. **B**, Percentage contribution of angiosperms, algae, fungi, bryophytes, ferns and lycophytes, and gymnosperms described as new to science between 2015 and 2020. Numbers of algae according to ALGAEBASE (https://www.algaebase.org/); Fungi according to recent descriptions available from mycological journals, Index Fungorum (http://www.indexfungorum.org), and Mycobank (https://www.mycobank.org); Bryophytes according to the Index Hepaticarum online (https://www.ville-ge.ch/musinfo/bd/cjb/hepatic/), recent publications and TROPICOS database (https://www.tropicos.org/name/Search); and angiosperms, gymnosperms, ferns, and lycophytes according to IPNI (International Plant Name Index, https://www.ipni.org/).

in Brazil, continuous efforts are needed to overcome the taxonomic impediment that prevents us from achieving goals beyond 2020. Below, we summarize key areas where efforts are most needed to overcome the taxonomic and geographic shortfalls that remain for flora and funga in Brazil.

Taxonomic identifications. — Reflecting the extraordinary diversity of the planet, taxonomic identifications may change multiple times over the lifetime of a specimen. Such changes may be simply to correct an erroneous initial identification or to add precision to the identification of a specimen originally named only to genus. Alternatively, they may result from changes in the circumscription of species or nomenclatural updates. As examples, there are specimens of Eriocaulaceae with more than 21 different identifications (see Reflora statistics), or cases like *Blepharocalyx salicifolius* (Kunth) O.Berg (Myrtaceae), which includes 90 synonyms; similarly, the genus *Cyperus* (Cyperaceae) possesses 49 published synonyms while the species *Cyperus odoratus* L. alone has 108 synonyms. Such cases are not unusual as species circumscriptions represent hypotheses that are constantly challenged and tested (Sluys, 2013).

The monographs that comprise the BF2020 are based directly or indirectly on data derived from preserved specimens, or less frequently on observations, both of which document the occurrence of individual species at a particular point in space and time. The integrity of these data is fundamental to the quality of the science based on those records. Conversely, errors and inaccuracies in the data undermine the value of taxonomic outputs as a basis for further research. Quantifying and addressing such errors and inaccuracies are central to maintaining and enhancing the utility of the BF2020. In fact, this project was created to enable the delivery of the advanced targets of the GSPC and the quality of the data included in BF2020 is crucial for conservation.

Apart from its importance for conservation, the breadth and depth of the BF2020 will influence the results and conclusions of academic research in fields such as ecology, evolution, and biogeography for decades to come. In fact, all research in the life sciences depends on high-quality taxonomy (sensu Ebach & al., 2011). Taxonomic misidentifications generate error cascades in the biological sciences, impacting environmental management and conservation. Accurate identifications of taxa also play fundamental roles in applied research such as plague identification, biochemistry, medicine, and pharmacological studies, among others (Bortolus, 2008). In this context, taxonomy is vital for biodiversity studies, and BF2020 provides the foundation for future research. The data generated will also provide the basis for extinction risk assessments of Brazil's plants and fungi, and for the selection of priority taxa and areas for *in* and *ex situ* conservation. In the interests of academic research and conservation action, the taxonomic, geographic, and temporal errors, inaccuracies, and gaps in the data underlying the BF2020 must be identified and addressed where possible, although temporal gaps cannot easily be addressed retroactively.

Taxonomic updates to physical collections and databases often lag behind specialist knowledge. The incomplete digitization of Brazil's collections, combined with constraints on resources for collections curation, leads to increasing discrepancies between physical, digital, and expert views on taxonomic identifications, complicating scientific and conservation decisions based on these resources. It is essential that funding for taxonomic experts to visit and update physical collections be maintained and expanded. This represents the best approach to maintaining and improving the taxonomic accuracy of specimen identifications.

Georeferencing. — Despite the colossal amount of taxonomic and distributional data made available digitally (DAI) over the past few decades, details of fewer than 10% of the world's 2 billion preserved specimens are available via data aggegators such as Global Biodiversity Information Facility (GBIF) using the Darwin Core Archive format (DwC-A) (Marcer & al., 2020). Furthermore, only about 55% of these occurrence records have coordinates; of these, barely a third (31%) include information about the uncertainty of the coordinates that is so essential for rigorous spatial analyses.

Brazil is no exception to this global pattern. Similar georeferencing deficits were identified in DAI for plant species endemic to the Brazilian Atlantic Forest, one of the best-documented phytogeographic domains in Brazil; 75% of occurrence records lacked valid spatial information and 22% of species lacked any spatial data in GBIF (Colli-Silva & al., 2020). This deficit of high-quality geospatial data is particularly concerning in light of the increasing tendency to estimate extinction risk based on DAI alone (e.g., Pelletier & al., 2018; Stévart & al., 2019; Robiansyah & Wardani, 2020). Such an approach tends not only to overstate the proportions of assessed species deemed threatened (by up to 50%), but also to overlook the species most likely to be threatened because their georeferenced occurrence records are often too few to meet thresholds for inclusion in such analyses (Nic Lughadha & al., 2019; Walker & al., 2019).

In short, there is no doubt that taxonomic data and accurately georeferenced data are essential for the accuracy of conservation assessments and for a chain of research in the life sciences (see more examples in Anderson & al., 2020). The lack of georeferenced data from specimens collected nowadays can be interpreted as a limited understanding on the part of the collectors of the needs of researchers in the life sciences. Collection managers should identify options to maximize the proportion of georeferenced material entering their collections. For example, since 1 January 2020, researchers at the Rio de Janeiro Botanical Garden wishing to deposit their collections at RB are required to include georeferenced locality data within their specimen labels. The same occurs in other herbaria, such as URM. Given that retrospective georeferencing of collections is recognized as a skilled and time-consuming process that is difficult to automate (Marcer & al., 2020), georeferencing should be mandatory for all collections. Nonetheless, the potential to increase the utility of existing biodiversity data makes retrospective georeferencing worth

pursuing (Hill & al., 2009). The volume of data now available in digital form offers exciting new opportunities to minimize duplication of effort across researchers and collections.

Neglected taxa and undersampled areas. — The BF2020 project produced high-quality taxonomic, geographical, and morphological data for 92% of all known Brazilian land plants, 6% of known algal species, and 5.5% of known fungi. Apart from the challenge of completing treatments for species already known to science but missing from the Brazilian Flora 2020, regular updates to the system will be required to incorporate newly described species: An average of 263 species of angiosperms, 16 species of ferns and lycophytes, and 6 species of bryophytes are described from Brazil each year (Fig. 3A). In this context, continued study of specimens already deposited in museum collections is urgently needed, complemented by additional fieldwork tackling neglected taxa and undersampled areas to achieve a more comprehensive picture of Brazilian biodiversity, especially in the least sampled regions of the country. Additional data are greatly needed to capture changes in species distributions over time and to fill critical gaps for taxa and areas that have been neglected.

Many endemic species are likely to go extinct before we can collect or describe them (Singh, 2002; Cheek & al., 2020; Raven & Miller, 2020). To address this issue, we should focus collection efforts on taxa with low sampling efforts or in undersampled areas (Antonelli & al., 2018; Paton & al., 2020; Stropp & al., 2020). For example, Amazonia remains the most undersampled region in the country (see Costa & al., 2020; Ritter & al., 2020; Stropp & al., 2020; Gomes-da-Silva & Forzza, 2021). Also undersampled are Brazil's mesophotic ecosystems (deep-water habitats), which are home to the most extensive beds of rhodoliths in the world. Studies on the cyanobacteria and algal floras of these regions are urgently needed (Soares & al., 2019, 2020; Spalding & al., 2019; Paton & al., 2020).

Although the last decade was marked by a peak in the description of new species of fungi (Cannon & al., 2018; Miralles & al., 2020), these organisms are among the most neglected on Earth. Of the estimated 2.2–3.8 million species of fungi globally (Hawksworth & Lücking, 2017), only 150,224 species have been described to date (Species Fungorum, 2020). Fewer than 40% of all Brazilian herbaria hold fungal collections, with the largest mycological collections with online data located in the northeastern (URM, c. 90,000 specimens), southeastern (SP, c. 40,000 specimens), and northern (INPA, c. 27,000 specimens) portions of the country (Maia & al., 2019; see Paton & al., 2020). The Amazon represents the most species-rich region for fungi worldwide (see Ritter & al., 2020), making investments in mycological research imperative in this region (Ritter & al., 2020). Likewise, the diversity of freshwater and marine algae is unequally studied, both taxonomically and geographically. Indeed, the existing documentation relies on localized surveys.

The maintenance and development of Brazilian herbaria and biodiversity systems. — The increasing availability of natural history collections through online databases has led to a steep increase in the use of digital collection data in research (Miralles & al., 2020). Although South America has a relatively high percentage of specimens digitized and available online when compared to other tropical continents, a large amount of primary data still awaits digitization and georeferencing (Paton & al., 2020). The Reflora project digitized and made freely available online c. 2.6 million out of the 6.7 million specimens deposited in Brazil's 216 herbaria (Gasper & al., 2020). Additional images from Brazilian herbaria are available through the INCT-Virtual Herbarium. However, most of the collections are only partially digitized, and 130 Brazilian collections have not even started to digitize their collections. The amount of digitized data available also differs substantially between taxonomic groups, a common pattern globally. For instance, only 55% of all known fungal species are represented in the GBIF data platform (https://www.gbif.org/), contrasting with the 82% of bryophyte species, and 90% of vascular plant species available through the same online data repository (see Paton & al., 2020).

The digitization of herbaria and fungaria confers many advantages to collections and facilitates data curation and access, both of which are crucial for the maintenance of high-quality collections (Paton & al., 2020). While the digitization of collections should be extended and accelerated as much as possible, a large proportion of collections lack accurate species-level identifications and/or geographic coordinates (Anderson & al., 2020), preventing the use of specimen data for biodiversity management and the sustainable use of biodiversity. In this context, improvement of data quality is also crucial to maximizing the potential of plant and fungal specimens to fill biodiversity gaps and effectively inform decision makers. However, improving data quality is highly dependent on resources and will rely on the availability of funds to maintain long-term national projects (see Anderson & al., 2020).

The regular inclusion of the newly described taxa into the Reflora Virtual Herbarium and the BF2020 is vital for the online system to remain relevant and useful in the years to come. Apart from updating the contents of the existing biodiversity platform, the inclusion of new data fields would allow the Brazilian Flora system to contribute to an even broader range of research fields and to better support the conservation and sustainable use of Brazil's unique biological resources. For instance, given the increasing importance of molecular data for biodiversity research (Miralles & al., 2020), Brazilian herbaria and fungaria can work towards increasing the amount of molecular information associated with specimens. Not only would an increased availability and integration of such data enhance species circumscriptions and expedite accurate identifications of taxa, it would also allow us to address a much broader range of research questions, and to meet multiple conservation challenges. By establishing standard protocols for the collection and storage of preserved genetic material (i.e., leaves preserved in silica gel) alongside the dried specimens, the value of individual specimens and collections would increase substantially (Lendemer & al., 2020).

Recognizing the value of taxonomic expertise and inspiring the next generation of taxonomists. — Although high-quality taxonomic data is fundamental to overcoming the biodiversity crisis (see examples in Bortolus, 2008), the field of taxonomy has been devalued in recent decades (Crisci & al., 2020; Pinto & al., 2021). Indeed, investigating and describing biodiversity is crucial for the future of humanity (Antonelli & al., 2020), and much of the progress achieved by both applied and basic research is contingent on the correct identification of taxa (Ebach & al., 2011; Crisci & al., 2020).

Over the past 12 years, Brazil's plant and fungal taxonomists have demonstrated their capacity to deliver high-quality scientific outputs in widely accessible forms in response to societal and global needs (Canteiro & al., 2019). The broad overview of Brazilian algae, fungal and plant diversity and the depth of the data that has resulted from these extraordinary endeavours has allowed scientists to identify research gaps and needs, as well as to establish future research goals more clearly. Taxonomists along with botanical and mycological collection managers showed that they are well-prepared to rise to the challenges inherent in these gaps, needs, and goals, provided they are adequately equipped and resourced.

Beyond the detailed inventory of the Brazilian flora and funga that resulted from the BF2020 project, this initiative also contributed to massive capacity building. Specifically, the project supported hundreds of graduate and undergraduate students to be trained and to conduct research alongside experienced taxonomists, greatly contributing to the development of the next generation of taxonomists. The team of committed and dedicated Brazilian botanists that participated in this project was also able to develop the competence and confidence to work closely with IT professionals on the development and maintenance of biodiversity information systems. These systems revolutionized Brazilian botany and collaboration patterns among Brazilian taxonomists, allowing botanists and mycologists to expand their scientific network considerably, both nationally and internationally. To maintain the research networks and expertise developed during this project, while also ensuring that taxonomic experts remain motivated to tackle further challenges, it is crucial that their contributions be explicitly recognized and matched by a commitment to support their work adequately going forward.

Notwithstanding the innumerable controversies concerning bibliometric measures in taxonomy, with the application of citation rules over timescales incompatible with the long citation half-life of taxonomic papers (see discussion in Crisci & al., 2020; Pinto & al., 2021), the lack of recognition and consequently the lower scores and impact factors of journals publishing alpha-taxonomic studies have discouraged the new generation of taxonomists. These negative effects may be offset to some extent by the inspirational work of the BF2020 team of taxonomists, which included many early-career taxonomists and demonstrated the direct relevance of the science of taxonomy to the global biodiversity challenges of which the younger generations are perhaps most acutely aware. Nonetheless, students need to be able to identify a viable career path if they are to commit to the many years of training required for a career in taxonomy (Drew, 2011).

Taxonomists themselves can and should contribute to a renewed appreciation of their profession and its outputs through an increased emphasis on the integration of descriptive morphology, ecological, and molecular data in the circumscription and formal description of new taxa, wherever possible (Baldini & al., 2021). Furthermore, studies of a purely descriptive nature lacking explicit hypotheses and replicable methods, or based on an insufficient number of individuals sampled, should be avoided as much as possible. On the other hand, since thousands of Brazilian plant and fungal species still await scientific description, including many narrow endemics threatened with extinction, it must be acknowledged that describing individual species new to science based on limited sampling will still be necessary; the alternative would be to delay describing such species, thereby making them effectively invisible for conservation priorities and action (Cheek & al., 2020). Nonetheless, taxonomists should strive to complement such species-specific publications with more inclusive treatments that place their unrivalled knowledge of the species they study in a broader framework, including replicable methods and explicit hypotheses (e.g., Martinez & al., 2020; Sassone & al., 2021) to yield novel findings and insights of immediate relevance to wider audiences.

Thus, the work of taxonomists must be updated, recognized, and valued by governmental programs such as the Brazilian program that aims to support capacity building in taxonomy (PROTAX, Programa de Apoio a Projetos de Pesquisas para a Capacitação e Formação de Recursos Humanos em Taxonomia Biológica), launched in 2005 by the Brazilian National Council for Scientific and Technological Development (i.e., CNPq, Conselho Nacional de Desenvolvimento Científico e Tecnológico). The maintenance of initiatives of this nature and the creation of new ones is crucial to ensure the continuity of biodiversity research in Brazil. The importance of taxonomy and taxonomists, i.e., the researchers responsible for describing biodiversity, needs to be broadly acknowledged and recognized.

■ CONCLUSIONS

The Brazil Flora Group is proud to have achieved Target 1 of the GSPC. This achievement is arguably even more significant at a time of "scientific reductionism", with botany and mycology suffering pervasive worldwide depreciation (Crisci & al., 2020), and the funding for both BF2020 and Reflora projects severely reduced by numerous budget cuts due to political and economic crises and changes in conservation polices in Brazil (Escobar, 2017, 2019; Casado & Londoño, 2019).

Brazil is home to the highest biodiversity and one of the highest endemism levels on Earth. Inventorying this megadiverse country is a difficult task that can only be achieved through collaborative efforts. The BF2020 project involved the partnership of 222 institutions and the hard work of 984 taxonomists from 27 countries (Fig. 4). All participants worked

Brazilian Flora 2020: Terminology, database contents, structure, and management

To evaluate the advances on the BF2020 conducted over the last 10 years, we explored data published in the Catalogue of Brazilian Plants and Fungi (Forzza & al., 2010a), BFG (2015), Costa & Peralta (2015), Maia & al. (2015), Menezes & al. (2015), Prado & al. (2015), and BFG (2018), as well as data compiled directly from the websites Reflora Virtual Herbarium (http://reflora.jbrj.gov.br/reflora/herbarioVirtual/) and Brazilian Flora 2020 (http://floradobrasil.jbrj.gov.br/).

The first step to build the BF2020 was an open call for proposals to monograph genera and/or families; this call was open from 10 March to 30 June 2015. The new working area of the online BF2020 system and its public webpage were launched on 17 February 2016, along with a call for proposals to treat taxa for which proposals had not been submitted during the first call; new proposals were continuously evaluated over the course of the project. Proposals were welcomed from individual scientists or collaborative teams, treating a maximum of 300 species per taxonomist. Families represented by 60 species or fewer in Brazil were required to be treated within a single proposal involving the same group of taxonomists. The new system module to input morphological characters included both "free-text fields" and "controlled fields". For vascular plant genera with two or more Brazilian species, the use of "controlled fields" was mandatory. These "controlled fields" were configured by the taxonomic specialist(s) who selected characters and their corresponding character states that enabled the identification of individual species or groups of species within genera or families. The configuration of characters and character-states was constrained by the system's glossary, which included c. 13,000 terms, all available in Portuguese, English, and Spanish.

Building on the strong foundation established by the Brazilian List 2010, taxonomists were asked to add new records, and new taxa, and to update the details of taxa already included in the system. Taxonomists were further requested to add detailed and standardized morphological descriptions, illustrations, nomenclatural data, geographic distributions, and keys for the identification of all taxa included in the online system. For more details on the methodology used by the Brazilian Flora 2020, see Forzza & al. (2010b) and BFG (2018).

Following BFG (2018), the Brazilian Flora 2020 platform treated a polyphyletic group composed of one lineage of photosynthetic prokaryotes and many lineages of auto- and heterotrophic photosynthetic eukaryotes (Baldauf, 2008; Ruggiero & al., 2015; Cavalier-Smith, 2018). However, for practical reasons and easy communication with non-scientists and governmental agencies, the Brazil Flora Group applied traditionally used names even though the current knowledge of the evolution of life might adopt a different taxon circumscription. For example, "algae" includes the flagellated-, micro- (diatoms), red-, golden-, brown-, green-, and blue-green algae, all of which are currently treated as the prokaryote group cyanobacteria and the eukaryote super-groups Excavata, Alveolata, Stramenopiles, and Archaeplastida (Baldauf, 2008; Ruggiero & al., 2015; Cavalier-Smith, 2018). Likewise, within the BF2020 system, the term "fungi" includes the true fungi (opisthokonts eukaryotes) and fungus-like mold eukaryotes, e.g., slime molds (amoebozoan of Ceratiomyxida and rhizarian of Plasmodiophorida) and water molds (stramenopiles of oomycetes) (Wijayawardene & al., 2020). Similarly, the term "bryophyte" is used in the "wide sense" and includes mosses, anthoceros, and hepatics. Finally, vascular plants (tracheophytes) include ferns, lycophytes, gymnosperms, and angiosperms. The term "plant" is used in BF2020 to encompass all embryophytes (from bryophytes to flowering plants), while "land plants" includes both the non-vascular bryophytes and the vascular land plants. Funga is used as an equivalent term to flora (Kuhar & al., 2018).

Data for new species of vascular plants described from Brazil between 2015 and 2020 were retrieved from the International Plant Name Index (IPNI, https://www.ipni.org/). Data for new species of bryophytes were retrieved from the literature, the Index Hepaticarum (https://www.ville-ge.ch/musinfo/bd/cjb/hepatic/), and TROPICOS (https://www.tropicos.org/name/Search); algae were retrieved from ALGAEBASE (https://www.algaebase.org/); and, data on new fungal species were obtained from recent descriptions available in mycological journals, from Index Fungorum (http://www.indexfungorum.org), and from Mycobank (https://www.mycobank.org).

Results reported here are based on data from the Brazilian Flora 2020 platform on 1 January 2021 (archived at http://ipt.jbrj.gov.br/jbrj/resource?r=lista_especies_flora_brasil&v=393.270). Geographic distribution data, federal states, and phytogeographic domains (termed "biomes" in Brazil) follow IBGE (2004).

within a single virtual environment that allowed them to freely exchange data, solve taxonomic problems, and improve the quality of the information produced. This massive association of taxonomic researchers is unprecedented for the inventory of a single country throughout the world, illustrating how the monumental task of inventorying megadiverse countries like Brazil can be achieved. The network of botanists involved in the project included professional taxonomists, students at many levels of education (undergraduate to post-doctorate), and professional researchers, most of which worked as volunteers, without receiving any payment for undertaking this task. Although all the researchers involved share the honour of having contributed to the completion of the BF2020, the number of unemployed researchers who worked on the production of this Flora reflects the limited interest of society and funding agencies in taxonomy, botanical, and mycological sciences in general.

The Brazilian Flora 2020 virtual system integrates data from plant and fungi collected in Brazil during the last two centuries,

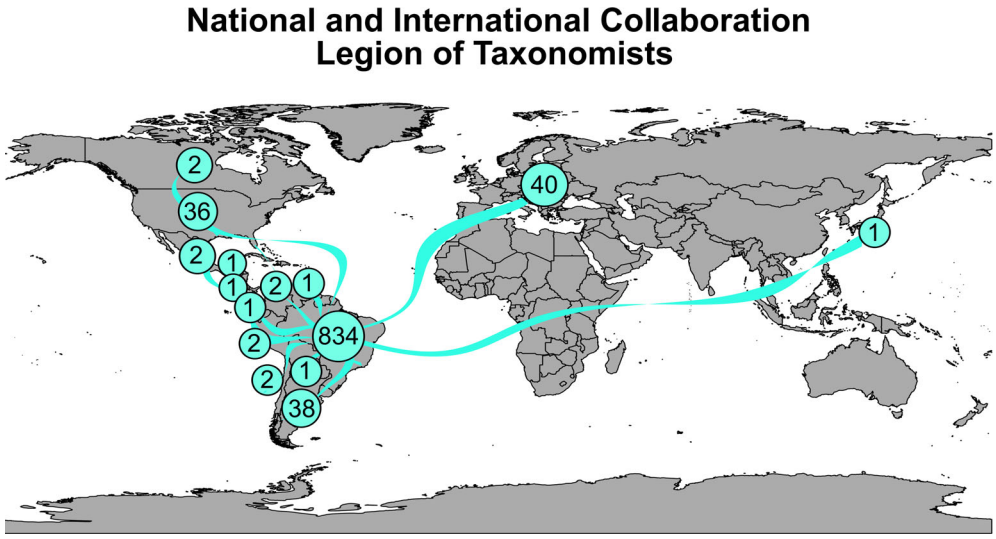

Fig. 4. Collaboration of Brazilian Flora Group Taxonomists. World map showing the distribution of the 984 national and international collaborators in the Brazilian Flora 2020 project by country: Argentina (38 taxonomists), Austria (1), Bolivia (1), Brazil (834), Canada (2), Chile (2), Colombia (2), Costa Rica (1), Denmark (1), Ecuador (1), England (12), Finland (1), France (2), Germany (7), Italy (1), Japan (1), Mexico (2), Netherlands (3), Panama (1), Peru (2), Portugal (1), Scotland (5), Spain (4), Sweden (1), Switzerland (1), United States (36), and Venezuela (1). Count performed per institution. Twenty taxonomists have no institution and therefore the sum of countries does not equal the total number of taxonomists.

casting light on the most recent numbers quantifying Brazilian biodiversity. By applying different filters to the database, anyone can obtain a verified taxonomic list of Brazilian species of algae, fungi, and plants for any Brazilian state, region, and/or biome. The system further provides data on the morphology and distribution of all taxa. Through this major effort, open and easily accessible expert-verified data are freely available to all users, minimizing the scarcity of primary data for algae, fungi, and plants of Brazil.

The comprehensive treatment of the BF2020 produced through this project will serve as basis for a chain of research in systematics, biogeography, and evolution, as well providing the basis for plant and fungal biodiversity management and conservation in Brazil. However, to effectively address the "gaps and future goals beyond 2020" outlined here, we need greater alignment and efforts between human resources, infrastructure, and collaborative networks, all of which require funding.

The concerted efforts of a legion of taxonomists proved to be effective in the task of documenting the world's most diverse country. Beyond celebrating the challenge overcome, we need to commit to continue to improve our knowledge of Brazil's diversity of algae, fungi, and plants from 2021 onwards. To keep the online Brazilian Flora up-to-date and scientifically accurate, a broader and more inclusive approach will be required, involving an even more collaborative team of taxonomists.

■ AUTHOR CONTRIBUTIONS

JGS and RCF designed the manuscript, compiled, organized, and analysed the data, produced figures and tables, wrote the first draft of the manuscript, revised, and approved its final version. ENL and LGL co-wrote the manuscript, revised, and approved its final version. FLRF, MRVB, JFAB, CEMB, TBC, MANC, AFC, DPC, ECD, PL, HCL, LCM, VFM, MM, MPM, CWNM, MN, DP, JP, NR, JRS, LSS, LTP, BMTW and GZ revised and approved its final version. All 982 national and international collaborators generated and reviewed data from original research on the Brazilian flora. — JGS, https://orcid.org/0000-0003-0817-186X; FLRF, https://orcid.org/0000-0002-0372-4325; MRVB, https://orcid.org/0000-0001-6166-3922; JFAB, https://orcid.org/0000-0003-3509-293X; CEMB, https://orcid.org/0000-0003-4030-9961; TBC, https://orcid.org/0000-0003-1649-9830; MANC, https://orcid.org/0000-0002-1246-4780; AFC, https://orcid.org/0000-0002-9200-4222; DPC, https://orcid.org/0000-0001-9495-3029; ECD, https://orcid.org/0000-0002-4661-0272; PL, https://orcid.org/0000-0002-5239-2048; HCL, https://orcid.org/0000-0003-2154-670X; LGL, https://orcid.org/0000-0003-4960-0587; LCM, https://orcid.org/0000-0003-0095-5758; VFM, https://orcid.org/0000-0002-7204-0744; MM, https://orcid.org/0000-0003-3363-1143; MPM, https://orcid.org/0000-0003-0872-8429; CWNM, https://orcid.org/0000-0003-1737-5792; ENL, https://orcid.org/0000-0002-8806-4345; DFP, https://orcid.org/0000-0003-4304-7258; JP, https://orcid.org/0000-0003-4783-3125; NR, https://orcid.org/0000-0002-2103-917X; JRS, https://orcid.org/0000-0002-9504-5441; LSS, https://orcid.org/0000-0002-0486-0898; LTP, https://orcid.org/0000-0002-1276-2083; BMTW, https://orcid.org/0000-0002-4196-9315; GZ, https://orcid.org/0000-0001-9150-229X; RCF, https://orcid.org/0000-0002-7035-9313

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