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Rio de Janeiro Botanical Garden: Biodiversity Conservation in a Tropical Arboretum

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Abstract: In light of increasing human impacts on natural areas and climate change, urgent action is required to accelerate species conservation efforts. Ex situ conservation has gained importance, yet the increasing endangered species challenge is magnified in botanic gardens, notably tropical ones, insufficient to safeguard such diverse flora. This study focused on the living collection of the arboretum at the Rio de Janeiro Botanical Garden, examining all cultivated specimens and institutional database records between January and July 2023. It cross-referenced the collection's composition with the Flora e Funga do Brasil list, as well as Red Lists, to reveal that the collection includes 6960 specimens representing 1420 species, with 60.6% of these species native to Brazil, belonging to 134 botanical families. The collection encompasses all Brazilian phytogeographic domains, with the Atlantic Forest and the Amazon having the highest number of species in cultivation. In terms of conservation efforts, the collection includes 83 species from the Brazilian Red List and 106 species from the IUCN Red List, contributing to the Global Strategy for Plant Conservation, Target 8. This evaluation is the first step toward identifying collection gaps, future planning, and targeting species for acquisition to enhance the effectiveness of our conservation efforts.

Keywords: biodiversity management; Brazilian flora; endangered species; living plant collection; plant conservation

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1. Introduction

In recent years, human activities within natural areas have significantly increased, putting considerable pressure on the environment [1]. Simultaneously, there has been a growing global interest in ex situ conservation efforts [2]. However, given the rapid pace of climate change and the degradation of natural habitats, there is an urgent need to accelerate conservation initiatives aimed at safeguarding biodiversity, encompassing both in situ and ex situ approaches [3,4].

Ex situ conservation provides a reliable and cost-effective approach to ensure the protection of species and genetic diversity. The germplasm stored within these repositories holds considerable value for species reintroduction endeavors [5]. Botanic gardens play a critical role in ex situ conservation by maintaining plant collections that encompass more than a third of the planet's taxa [6], underscoring their concrete importance and potential. However, a significant disparity exists between the number of endangered species and the capacity of botanic gardens to cultivate them [3]. Furthermore, a global imbalance is evident when considering the global distribution of plant diversity and the limited number of botanic gardens equipped to sustain these species within their native climatic conditions [7].

Regrettably, only 20% of all botanic gardens globally are situated in tropical regions, many of which are located within biodiversity hotspots, further amplifying the significance of the role played by tropical botanic gardens [7]. Consequently, temperate species have a 60% likelihood of being cultivated within the botanic garden network, while their tropical counterparts have only a 25% chance [4].

Brazil has mega biodiversity, hosting approximately 34,500 native vascular plant species and two hotspots, the Atlantic Forest and the Cerrado [8,9]. Safeguarding this richness is a monumental task that requires great responsibility. Unfortunately, the number of national botanic gardens in Brazil is also limited and unevenly distributed across the country [10]. Furthermore, to fully realize the potential of these institutions to contribute to biodiversity efforts, it is necessary to evaluate the collections they contain [11]. Several criteria can be employed to assess the value of a collection, including factors like heritage value, phylogenetic distinctiveness, climate suitability, and utility, all of which complement the assessment of endangerment value [12].

Situated within the Atlantic Forest hotspot, the genesis of the Rio de Janeiro Botanical Garden (JBRJ) is intertwined with explorations during the Portuguese colonial period. Concurrently with their pursuit of understanding and harnessing native species, the Portuguese introduced exotic specimens, particularly oriental spices, timber species, and resources like paints, sugar, fibers, and roots. The aim of this deliberate introduction was to acclimate, cultivate, and study these species, thereby unlocking their potential for applications in agriculture, trade, and scientific enrichment [13].

During the early years of its establishment, the collection saw the incorporation of diverse exotic species, including breadfruit (*Artocarpus altilis* (Parkinson) Fosberg), cinnamon (*Cinnamomum verum* J. Presl), clove tree (*Syzygium aromaticum* (L.) Merr. and L.M.Perry), horse-radish tree (*Moringa oleifera* Lam.), lychee (*Litchi chinensis* Sonn.), nutmeg (*Myristica fragrans* Houtt.), pepper (*Piper nigrum* L.), star fruit (*Averrhoa carambola* L.), and sugarcane (*Saccharum officinarum* L.) [14].

By 1890, Barbosa Rodrigues, the JBRJ director at the time, conducted an inventory of the collection. He found that, at the beginning of his tenure, there were between 450 and 500 plant species under cultivation, most of them exotic, with some represented by hundreds of specimens, totaling about 50,000 specimens [15]. During his administration, a decisive shift in focus emerged through a decree that demonstrated a newfound interest in native Brazilian flora. This shift was marked by the appointment of correspondents in various Brazilian states, who were tasked with contributing species to the JBRJ collection in a concerted effort to comprehensively represent the national flora [16]. However, the composition of the collection has exhibited significant fluctuations over its history, experiencing phases of notable expansion in diversity alongside periods marked by substantial losses of specimens. These losses were particularly pronounced during severe natural events, including major floods like those of 1906 [17] and 1936 [18], as well as droughts such as the one in 1914/15 [19].

Welcoming an annual average of 500,000 visitors, JBRJ spans a total area of 143.98 hectares. In situ conservation takes place across 85.18 hectares, encompassing an area of the Atlantic Forest adjacent to the Tijuca National Park [20]. Ex situ conservation spans 38.8 hectares, following recent expansions in the cultivated landscape area (Figure 1). The upkeep of the JBRJ arboretum is directly managed by a workforce of approximately 60 individuals, including gardeners and other staff members. Moreover, the collection benefits from the expertise of numerous specialists, both within various directorates of the JBRJ and external to the institution, who contribute to specimen identification and utilize the collection for educational and research endeavors. With a legacy spanning over two centuries and operating under the direct auspices of the Ministry of the Environment and Climate Change, JBRJ's official mission is to "Promote, undertake and disseminate scientific research with an emphasis on plants, with a view of conserving and valuing biodiversity, as well as carrying out activities to promote the integration of science, education, culture, and nature" [21].

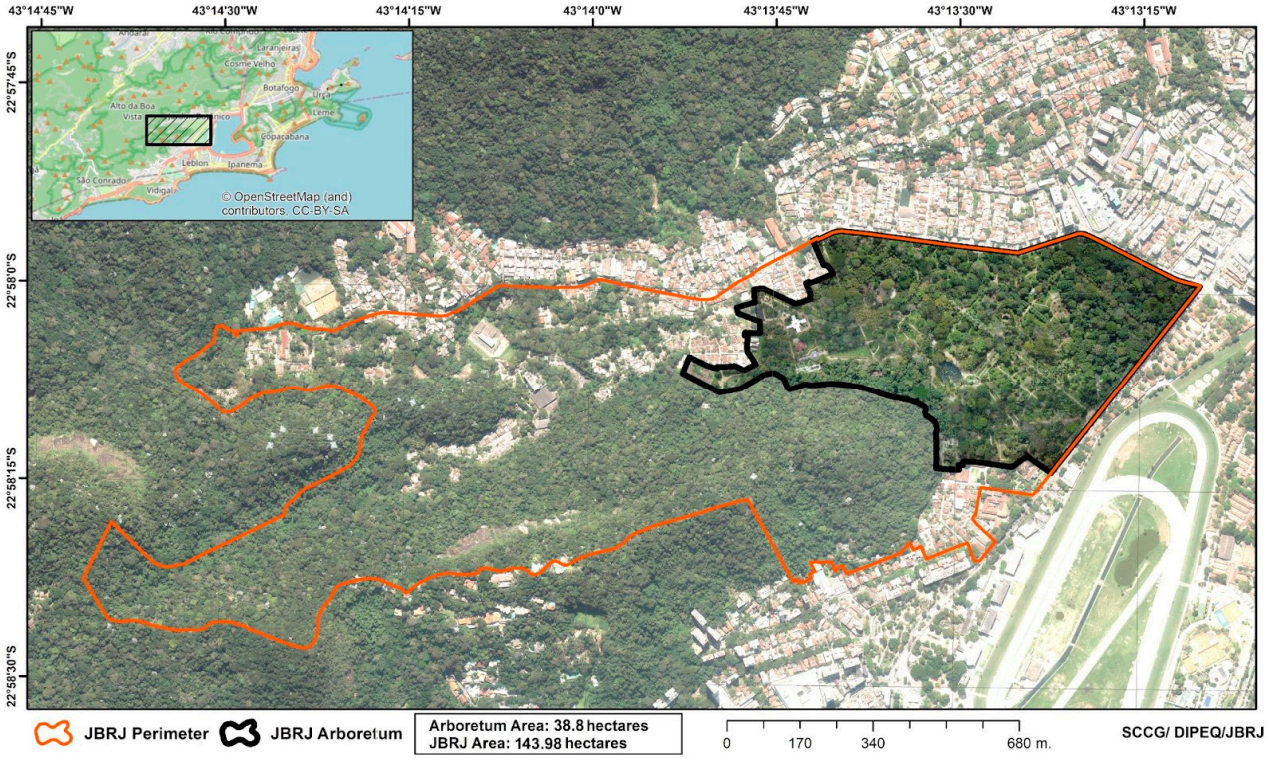

Figure 1. Total area of the Rio de Janeiro Botanical Garden (orange line) encompassing the in situ and ex situ area (black line).

The institution aims to cultivate informed citizens via environmental education based on biodiversity conservation and socio-environmental sustainability. In recent years, it has served 4800 students and has trained 470 teachers annually. Additionally, the institution has a socio-environmental responsibility center that trains young people in vulnerable socio-economic situations, offering courses that enable them to work as gardeners, environmental agents, administrative assistants, ecotourism guides, and to pursue a career through scientific initiation, supporting approximately 120 young people per year.

Since the last survey of this collection conducted two decades ago [22], significant developments have transpired, including the adoption of JABOT [23], a new database system [24], and the establishment of an institutional living collections policy. In light of these developments, a thorough assessment of the collection, such as the one presented here, becomes essential for advancing the efficient curation of a collection with a conservation, educational, and research mandate, particularly focused on native species, especially those facing endangerment within a mega-biodiverse country. This paper serves to present and discuss the composition of this collection, accentuating its role in contributing to the achievement of the goals outlined in the Global Strategy for Plant Conservation (GSPC) Target 8, which seeks to have a minimum of 75% of threatened plant species within ex situ collections, preferably within their country of origin, and at least 20% available for recovery and restoration programs [25].

2. Materials and Methods

The living plant collection at JBRJ is spread across areas, including the arboretum beds, which encompass the rose garden, the sensory garden, and the Japanese garden, and themed collections such as Bromeliads, Cacti and Succulents, Ferns, Orchids, the Shade Collection (encompassing Araceae and Marantaceae), Carnivorous Plants, and Medicinal Plants. The arboretum is an outdoor landscaped area dedicated to the cultivation and display of arboreal plants and climbers, with shrubs and herbaceous plants in its understory. Themed collections are nurtured in greenhouses and designated areas within the institutional arboretum. The plants grown in the arboretum beds, referred to as the

arboretum collection, along with the distinct themed collections, each maintain their own database and are overseen by specialized teams catering to the unique needs of each group. In this study, we focused on the arboretum collection; therefore, data from the aforementioned themed collections situated within the arboretum area were not included.

Our investigation commenced with an initial analysis, involving a comprehensive examination of specimens cultivated in the planting beds, which was performed between January and July 2023. Concurrently, we cross-referenced this information with their corresponding entries in the institutional digital database and mapping system, known as JABOT [23]. Throughout this process, we ensured that the records accurately reflected the living status of each plant, and we introduced new entries into the database so that the system best captured the reality observed within the cultivated plant collection.

Subsequently, we undertook a revision of the names recorded in the database to eliminate any discrepancies that could potentially impact the analysis. This revision adhered to the taxonomic framework outlined by APG IV [26]. As a reference for Brazilian species, we consulted Flora e Funga do Brasil [8], while for exotic species, we relied on Plants of the World Online [27] and the Tropicos Database [28].

For this assessment, we elected to classify the cultivated specimens into six habit-based categories: tree, palm tree, shrub, grass, vine, and bamboo; and we considered species listed on the Brazilian Red List [29], the IUCN Red List [30] and other Red Lists compiled within the BGCI ThreatSearch tool as endangered [31].

We performed a quantitative analysis to delineate the attributes of the living collection. These included the distribution across botanical families, the count of cultivated taxa, the proportion of native species, the representation of distinct biogeographical domains, and the number of endangered species both with and without documented provenance data.

3. Results

The JBRJ arboretum contains 215 planting beds distributed in 41 sections. Diverse aesthetics prevail across its area; the ground cover comprises various species, with a predominance of grasses. In the beds intended for Restinga (coastal vegetation), beach sand is the predominant substrate, and there are no ground cover plants (Scheme 1).

The arboretum collection currently comprises 6960 specimens from 1647 taxa, including 1420 species and nine hybrids (Supplementary Table S1). The native species in cultivation add up to 861 (60.6% of the total), while the exotic ones are 559 (39.4%).

It is noteworthy that in cultivation, *Roystonea oleracea* (Jacq.) O. F. Cook (Arecaceae, 542 specimens), *Mangifera indica* L. (Anacardiaceae, 101 specimens), and *Calycophyllum spruceanum* (Benth.) K.Schum. (Rubiaceae, 89 specimens) are the three most abundant species, as they are commonly seen along the arboretum's historic alleys. However, it is concerning that 661 species, accounting for 46.5% of the total, are represented by only a single specimen in cultivation.

After conducting a thorough evaluation of the plant habits at the arboretum, it was determined that 55% of the specimens are trees, which results in a landscape with a predominance of shade and the green of the canopies. Additionally, 24% of the specimens were identified as palm trees, while 9.3% were classified as shrubs. A smaller percentage of the specimens were found to be herbs (7.8%), vines (2.7%), and bamboos (1.2%).

In our collection, we have identified 83.1% of the specimens at the species or infraspecies level, 8% at the genus level, and 5.3% at the family level. However, there are still 3.6% of specimens that remain undetermined, which amounts to a total of 252 specimens. When it comes to botanical families, there are 134 of them in total. The top three most representative families are Leguminosae with 252 species, Arecaceae with 154 species, and Myrtaceae with 78 species. However, if we focus on only the native species of the top ten botanical families in terms of diversity in cultivation, we can see their representativeness regarding the Brazilian flora varies. Among the most abundant families in cultivation, Arecaceae and Sapotaceae have the highest representation, while Rubiaceae and Euphorbiaceae are the least representative (Table 1).

Scheme 1. Different planting locations in the arboretum. (**A**) Royal palm alley; (**B**) Frei Leandro Lake; (**C**) Amazon region beds; (**D**) Restinga vegetation beds.

Table 1. Top 10 botanical families with a larger diversity of species in cultivation, number of native species in cultivation, number of species in Brazil [8], and percentage of representation of the native flora by respective families.

Botanical Family	Total spp. in Cultivation	Native spp. in Cultivation	Species Richness in Brazil	Percentage of Representation of Brazilian Species
Leguminosae	252	195	2899	6.73%
Arecaceae	154	55	416	13.22%
Myrtaceae	78	61	1063	5.74%
Malvaceae	72	51	864	5.90%
Bignoniaceae	54	36	414	8.69%
Apocynaceae	39	19	814	2.33%
Araceae	36	26	524	4.96%
Rubiaceae	34	18	1475	1.22%
Euphorbiaceae	31	18	972	1.85%
Sapotaceae	31	25	247	10.12%

The arboretum houses a rich tapestry of diverse histories, where species are arranged in planting beds based on botanical families, phytogeographical domains, or other thematic approaches. The arrangement of species into botanical families is a practice dating back to the establishment of the arboretum [32,33], and continues to influence the layout of the beds even today. While just 4 out of the 215 beds are exclusively composed of a single botanical family—three beds with Arecaceae and a small bed with Theaceae—many of the remaining beds exhibit a prevailing, though not exclusive, presence of various botanical

families. We highlight the flowerbeds where there is a predominant presence of botanical families, with a grouping representing more than 30% of the flowerbed's content, along with their respective representation percentages (Table 2). Additionally, the figure depicts the thematic regions of the Amazon, Cerrado, and Restinga (Figure 2).

Table 2. Botanical families that predominate in arboretum beds and their respective beds.

Botanical Family	Percentage of the Family in the Planting Bed	Planting Bed with Greater Family Diversity	Number of Species (Number of Specimens) in the Bed from the Predominant Family
Arecaceae	87.30%	3A	48 (98)
Leguminosae	84.00%	14A	84 (118)
Myrtaceae	78.60%	8C	33 (45)
Moraceae	72.20%	29B	13 (23)
Rubiaceae	69.60%	1B	16 (21)
Apocynaceae	68.2%	11C	15 (24)
Convolvulaceae	66.60%	5H	4 (6)
Marantaceae	61.90%	15C	26 (81)
Euphorbiaceae	57.10%	30E	8 (18)
Malvaceae	52.40%	22C	11 (14)
Araceae	46.20%	17B	24 (44)
Asparagaceae	45.20%	38A	14 (50)
Rutaceae	40.60%	8A	13 (17)
Acanthaceae	38.90%	31A	7 (13)
Lamiaceae	37.50%	5C	6 (11)
Clusiaceae	36.80%	24A	7 (13)
Sapotaceae	35.20%	10A	19 (25)
Melastomataceae	34.60%	17C	9 (15)
Aquifoliaceae	33.30%	5J	5 (11)
Nymphaeaceae	33.30%	35C	4 (4)
Simaroubaceae	33.30%	5I	4 (4)
Bignoniaceae	30.80%	33A	12 (22)
Asteraceae	30.00%	18A	9 (9)
Pandanaceae	30.00%	3C	6 (15)

The distinctive characteristics of the Amazon region within the arboretum remain prominently evident in contemporary times. Among the 272 species documented across the collective range of the Amazon region beds, 136 species are native to the Amazon, with the presence of 63 species that can be exclusively found within this ecosystem. These numbers are anticipated to be even more substantial upon the formation of these beds, considering the numerous species being lost in cultivation due to challenges in acclimatization within the garden [13] and the significant flood event that transpired in 1936 [34].

The Cerrado bed also continues to exist within the arboretum, although it deviates from the anticipated characteristics of a true Cerrado, which typically features savanna-type vegetation [35]. Despite being composed of species from this phytogeographic domain, the plants under varying environmental conditions have led to a physiognomy that bears little resemblance to the typical Cerrado appearance. Among the 59 cultivated species in this planting bed, 37 are native to the Cerrado, with three being exclusive to this domain.

Furthermore, a different thematic concept was implemented in 1935 through the establishment of the Japanese Garden in the arboretum. This garden was crafted using 65 seedlings of iconic Japanese species, contributed during a visiting Japanese mission to Brazil [34]. Nonetheless, our assessment has unveiled that among the 42 species currently nurtured within the collective beds comprising this garden, only 7 occur naturally in Japan. On the contrary, 15 are exotic and found in other countries, while 20 are native to Brazil.

It is interesting to note that there are a wide variety of species being cultivated in the collection, ranging across all Brazilian phytogeographical domains. The Atlantic Forest is particularly well represented, with 618 species, followed by the Amazon with 419 species, Cerrado with 363 species, Caatinga with 233 species, Pantanal with 91 species, and Pampa with 78 species, as shown by the data compiled in Figure 3. This ranking seems to align with the diversity of vascular plants species found in the respective domains in Brazil; although the Pampa ranks fifth in the country regarding vascular species richness, it drops to the sixth position in arboretum diversity [8]. This discrepancy can be attributed to prevailing differences in climatic conditions, which present challenges for species adaptation within the arboretum environment.

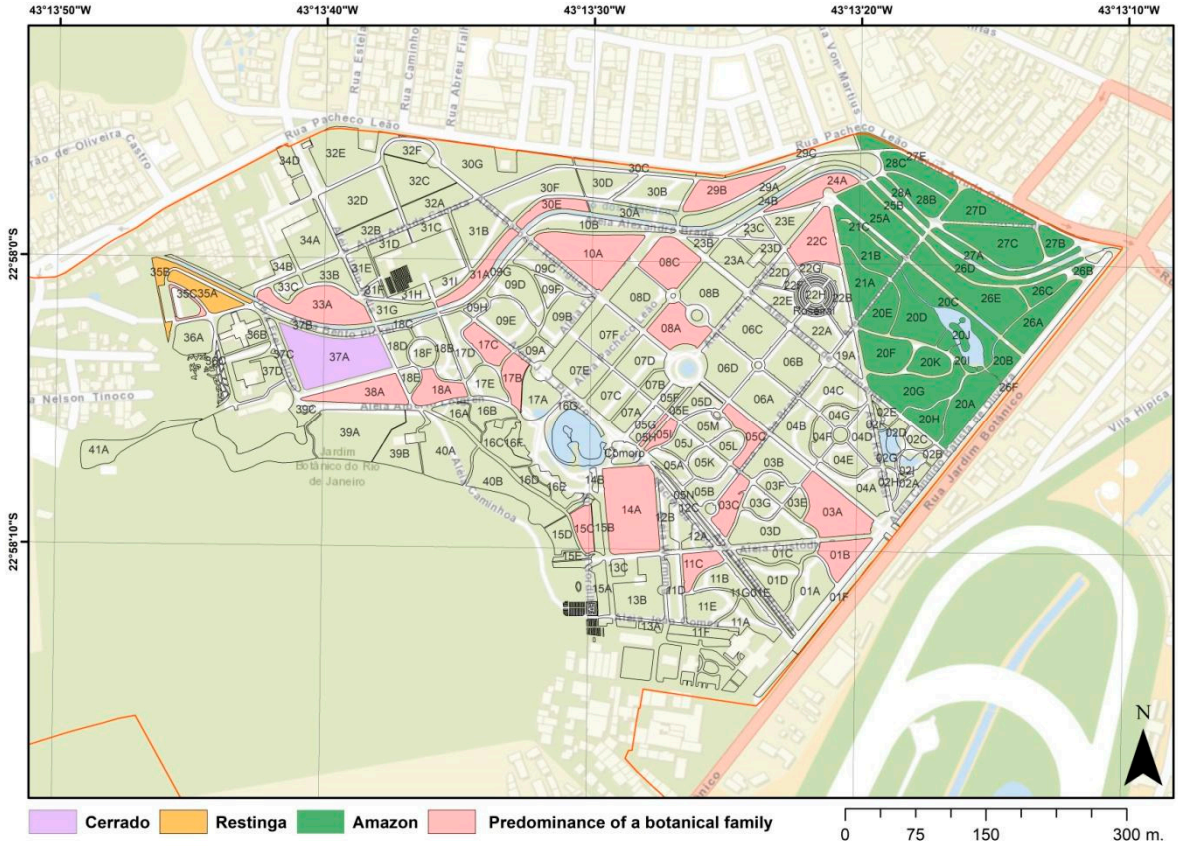

Figure 2. Arboretum map indicating the beds where there is a predominance of a botanical family, as well as the Amazon, Cerrado, and Restinga beds.

Concerning the conservation of native species, 83 species within the collection are currently under threat of extinction, as indicated by the Brazilian Red List [29]. These include five species that are considered Critically Endangered (CR), 51 that are Endangered (EN), and 27 that are Vulnerable (VU). Of these, 38 have provenance data known and are registered in the database; for the others, research into historical records can uncover their origin for inclusion in the database. When comparing the collection to the IUCN Red List [30], there are a total of 106 endangered species that are being cultivated, which includes one species listed as Extinct in the Wild (EW), 16 CR, 42 EN, and 47 VU. Out of these species, 29 have known provenance in the database. When combining both the

Brazilian Red List and the IUCN Red List, a total of 148 species are considered endangered, with 110 native to Brazil and 49 having known provenance data registered in the database system (Table 3).

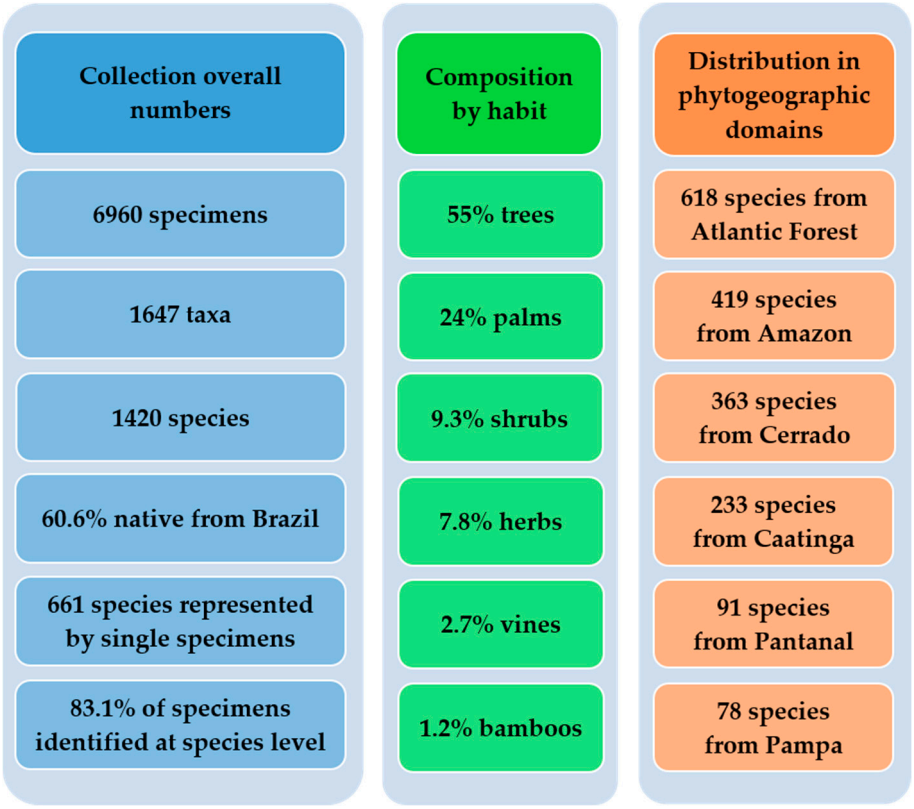

Figure 3. Compiled data on the JBRJ arboretum collection.

Table 3. Endangered cultivated species in the arboretum, their native-to-Brazil status, respective threat categories according to the Brazilian Red List [29] and the IUCN Red List [30], and the existence of known provenance data in the institutional database (JABOT).

Species	Native to Brazil	Brazilian Red List	IUCN Red List	Known Provenance in Database
Apocynaceae *Aspidosperma parvifolium* A. DC.	yes	EN		no
Apocynaceae *Aspidosperma polyneuron* Müll. Arg.	yes		EN	no
Araceae *Philodendron gloriosum* André	no		VU	no
Araucariaceae *Araucaria angustifolia* (Bertol.) Kuntze	yes	EN	CR	yes
Arecaceae *Acanthophoenix rubra* (Bory) H. Wendl.	no		CR	no
Arecaceae *Adonidia merrillii* (Becc.) Becc.	no		VU	no
Arecaceae *Bentinckia nicobarica* (Kurz.) Becc.	no		EN	no
Arecaceae *Butia capitata* (Mart.) Becc.	yes	VU		no
Arecaceae *Butia purpurascens* Glassman	yes	EN	VU	yes
Arecaceae *Butia yatay* (Mart.) Becc.	yes	VU		no
Arecaceae *Calamus ciliaris* Blume	no		VU	no
Arecaceae *Dictyosperma album* var. *conjugatum* H. E. Moore and Guého	no		CR	no
Arecaceae *Dypsis decaryi* (Jum.) Beentje and J. Dransf.	no		VU	no
Arecaceae *Euterpe edulis* Mart.	yes	VU		no
Arecaceae *Hyophorbe lagenicaulis* (L.H.Bailey) H. E. Moore	no		CR	no
Arecaceae *Hyophorbe verschaffeltii* H. Wendl.	no		CR	no

Table 3. *Cont.*

Species	Native to Brazil	Brazilian Red List	IUCN Red List	Known Provenance in Database
Arecaceae *Latania lontaroides* (Gaertn.) H. E. Moore	no		EN	no
Arecaceae *Ravenea rivularis* Jum. and H. Perrier	no		VU	no
Arecaceae *Sabal bermudana* L. H. Bailey	no		EN	no
Arecaceae *Sabal causiarum* (O. F. Cook) Becc.	no		VU	no
Arecaceae *Syagrus botryophora* (Mart.) Mart.	yes	VU		yes
Arecaceae *Syagrus macrocarpa* Barb. Rodr.	yes	EN	EN	yes
Arecaceae *Syagrus picrophylla* Barb. Rodr.	yes	VU		yes
Arecaceae *Tahina spectabilis* J. Dransf. and Rakotoarin.	no		CR	no
Asparagaceae *Beaucarnea recurvata* Lem.	no		CR	no
Asparagaceae *Dracaena umbraculifera* Jacq.	no		CR	no
Asteraceae *Stifftia fruticosa* (Vell.) D. J. N.Hind and Semir	yes	VU		no
Bignoniaceae *Ekmanianthe longiflora* (Griseb.) Urban	no		EM	no
Bignoniaceae *Handroanthus arianeae* (A. H. Gentry) S.Grose	yes	EN		yes
Bignoniaceae *Handroanthus cristatus* (A. H. Gentry) S.Grose	yes	EN		yes
Bignoniaceae *Handroanthus incanus* (A. H. Gentry) S.Grose	yes		VU	no
Bignoniaceae *Handroanthus riodocensis* (A. H. Gentry) S.Grose	yes	EN		yes
Bignoniaceae *Handroanthus serratifolius* (Vahl) S. Grose	yes		EN	no
Bignoniaceae *Jacaranda mimosifolia* D. Don	no		VU	no
Bignoniaceae *Paratecoma peroba* (Record) Kuhlm.	yes	EN		no
Bignoniaceae *Zeyheria tuberculosa* (Vell.) Bureau ex Verl.	yes		VU	no
Bromeliaceae *Aechmea castanea* L. B. Sm.	yes	EN		yes
Bromeliaceae *Alcantarea glaziouana* (Leme) J. R. Grant	yes	EN		yes
Burseraceae *Aucoumea klaineana* Pierre	no		VU	no
Calophyllaceae *Kielmeyera aureovinosa* M. Gomes	yes	EN		yes
Calophyllaceae *Kielmeyera rizziniana* Saddi	yes	EN	EN	no
Canellaceae *Cinnamodendron axillare* Endl. ex Walp.	yes	EN	EN	no
Chrysobalanaceae *Couepia schottii* Fritsch	yes	EN	VU	yes
Clusiaceae *Clusia diamantina* Bittrich	yes	EN	EN	no
Combretaceae *Terminalia acuminata* (Allemão) Eichler	yes	EN	EN	no
Combretaceae *Terminalia hoehneana* (N.F.Mattos) Gere and Boatwr.	yes		VU	yes
Cycadaceae *Cycas circinalis* L.	no		EN	no
Dichapetalaceae *Tapura follii* Prance	yes	CR	CR	yes
Dichapetalaceae *Tapura wurdackiana* Prance	yes	EN	EN	yes
Dioscoreaceae *Dioscorea pseudomacrocapsa* G. M. Barroso et al.	yes	EN		no
Erythroxylaceae *Erythroxylum ovalifolium* Peyr.	yes	VU		yes
Euphorbiaceae *Joannesia princeps* Vell.	yes		VU	no
Ginkgoaceae *Ginkgo biloba* L.	no		EN	yes
Iridaceae *Neomarica northiana* (Schneev.) Sprague	yes	EN		yes
Lamiaceae *Tectona grandis* L.f.	no		EN	no
Lauraceae *Aniba rosiodora* Ducke	yes	EN	EN	no
Lecythidaceae *Bertholletia excelsa* Bonpl.	yes	VU	VU	no
Lecythidaceae *Cariniana ianeirensis* R. Knuth	yes	EN	EN	yes
Lecythidaceae *Cariniana legalis* (Mart.) Kuntze	yes	EN	VU	no
Lecythidaceae *Couratari asterotricha* Prance	yes	EN	CR	yes
Lecythidaceae *Couratari pyramidata* (Vell.) Kunth	yes	EN	EN	yes
Lecythidaceae *Gustavia gracillima* Miers	no		VU	yes
Leguminosae *Amburana acreana* (Ducke) A. C. Sm.	yes	VU	VU	no
Leguminosae *Amburana cearensis* (Allemão) A. C. Sm.	yes		EN	no
Leguminosae *Apuleia leiocarpa* (Vogel) J. F. Macbr.	yes	VU		no
Leguminosae *Arapatiella psilophylla* (Harms) R. S. Cowan	yes		VU	no
Leguminosae *Browneopsis macrofoliolata* Klitg.	no		CR	no

Table 3. *Cont.*

Species	Native to Brazil	Brazilian Red List	IUCN Red List	Known Provenance in Database
Leguminosae *Centrolobium paraense* Tul.	yes	EN		no
Leguminosae *Chloroleucon tortum* (Mart.) Pittier	yes		CR	no
Leguminosae *Dalbergia nigra* (Vell.) Allemão ex Benth.	yes	VU	VU	no
Leguminosae *Dimorphandra exaltata* Schott	yes	EN	EN	no
Leguminosae *Dimorphandra wilsonii* Rizzini	yes	EN	CR	yes
Leguminosae *Dinizia jueirana-facao* G. P. Lewis and G. S. Siqueira	yes	CR	CR	yes
Leguminosae *Dipteryx alata* Vogel	yes		VU	yes
Leguminosae *Elizabetha speciosa* Ducke	yes	VU	VU	no
Leguminosae *Gleditsia amorphoides* (Griseb.) Taub.	yes	VU		no
Leguminosae *Grazielodendron rio-docensis* H. C. Lima	yes	EN		yes
Leguminosae *Harleyodendron unifoliolatum* R. S. Cowan	yes	EN	EN	no
Leguminosae *Inga cordistipula* Mart.	yes	VU	VU	no
Leguminosae *Inga hispida* Schott ex Benth.	yes		VU	yes
Leguminosae *Inga maritima* Benth.	yes	EN	EN	yes
Leguminosae *Luetzelburgia trialata* (Ducke) Ducke	yes	EN		no
Leguminosae *Machaerium legale* (Vell.) Benth.	yes	CR		yes
Leguminosae *Machaerium obovatum* Kuhlm. and Hoehne	yes	VU		no
Leguminosae *Machaerium villosum* Vogel	yes		VU	no
Leguminosae *Martiodendron fluminense* Lombardi	yes	EN		no
Leguminosae *Muellera filipes* (Benth.) M. J. Silva and A. M. G. Azevedo	yes	VU	VU	no
Leguminosae *Muellera virgilioides* (Vogel) M. J. Silva and A. M. G. Azevedo	yes	VU	VU	yes
Leguminosae *Paubrasilia echinata* (Lam.) Gagnon, H.C.Lima and G.P.Lewis	yes	EN	EN	yes
Leguminosae *Peltogyne discolor* Vogel	yes	VU		no
Leguminosae *Peltogyne mattosiana* Rizzini	yes	EN		no
Leguminosae *Pericopsis elata* (Harms) Meeuwen	no		EN	no
Leguminosae *Pterocarpus indicus* Willd.	no		EN	no
Lythraceae *Lafoensia replicata* Pohl	yes		VU	no
Malpighiaceae *Stigmaphyllon vitifolium* A. Juss.	yes	CR		no
Malvaceae *Abutilon anodoides* A. St.-Hil. and Naudin	yes	EN		yes
Malvaceae *Adansonia grandidieri* Baill.	no		EN	no
Malvaceae *Pseudobombax petropolitanum* A. Robyns	yes	EN	EN	no
Marantaceae *Goeppertia tuberosa* (Vell.) Borchs. and S. Suárez	yes	EN		no
Marantaceae *Goeppertia widgrenii* (Körn.) Borchs. and S. Suárez	yes	EN		no
Marantaceae *Ischnosiphon ovatus* Körn.	yes	EN		no
Melastomataceae *Merianthera pulchra* Kuhlm.	yes	VU		yes
Meliaceae *Cedrela fissilis* Vell.	yes	VU	VU	yes
Meliaceae *Cedrela odorata* L.	yes	VU	VU	no
Meliaceae *Khaya senegalensis* (Desr.) A. Juss.	no		VU	no
Meliaceae *Swietenia humilis* Zucc.	no		EN	no
Meliaceae *Swietenia macrophylla* King	yes	VU	VU	yes
Meliaceae *Trichilia casaretti* C. DC.	yes		VU	no
Moraceae *Ficus cyclophylla* (Miq.) Miq.	yes		EN	no
Moraceae *Sorocea guilleminiana* Gaudich.	yes		VU	yes
Musaceae *Musa coccinea* Andrews	no		EN	no
Myristicaceae *Virola bicuhyba* (Schott ex Spreng.) Warb.	yes	EN		no
Myristicaceae *Virola surinamensis* (Rol. ex Rottb.) Warb.	yes	VU	EN	no
Myrtaceae *Campomanesia hirsuta* Gardner	yes	EN	EN	yes
Myrtaceae *Campomanesia phaea* (O.Berg) Landrum	yes		VU	no
Myrtaceae *Eucalyptus deglupta* Blume	no		VU	no

Table 3. *Cont.*

Species	Native to Brazil	Brazilian Red List	IUCN Red List	Known Provenance in Database
Myrtaceae *Eugenia itaguahiensis* Nied.	yes	EN		no
Myrtaceae *Eugenia mattosii* D. Legrand	yes	EN	EN	yes
Myrtaceae *Eugenia pulcherrima* Kiaersk.	yes	VU	VU	no
Myrtaceae *Myrcia aethusa* (O.Berg) N. Silveira	yes		VU	yes
Myrtaceae *Myrcia carioca* A.R.Lourenço and E. Lucas	yes	VU	VU	no
Myrtaceae *Myrcia ovata* Cambess.	yes		VU	yes
Myrtaceae *Plinia edulis* (Vell.) Sobral	yes	VU		no
Myrtaceae *Plinia renatiana* G.M.Barroso and Peixoto	yes	EN		yes
Myrtaceae *Plinia spiritosantensis* (Mattos) Mattos	yes	EN		yes
Podocarpaceae *Podocarpus sellowii* Klotzsch ex Endl.	yes		EN	no
Polygonaceae *Coccoloba gigantifolia* Melo, Cid Ferreira and Gribel	yes	EN		yes
Proteaceae *Macadamia ternifolia* F. Muell.	no		EN	no
Rubiaceae *Coffea arabica* L.	no		EN	no
Rubiaceae *Riodocea pulcherrima* Delprete	yes	EN		yes
Rubiaceae *Simira eliezeriana* Peixoto	yes	EN	EN	yes
Rutaceae *Esenbeckia leiocarpa* Engl.	yes		VU	no
Salicaceae *Xylosma glaberrima* Sleumer	yes	VU		no
Santalaceae *Acanthosyris paulo-alvinii* G. M. Barroso	yes	CR		no
Sapotaceae *Chrysophyllum imperiale* (Linden ex K. Koch and Fintelm.) Benth. and Hook.	yes	EN	EN	yes
Sapotaceae *Chrysophyllum paranaense* T. D. Penn.	yes		VU	yes
Sapotaceae *Chrysophyllum splendens* Spreng.	yes		VU	no
Sapotaceae *Manilkara bella* Monach.	yes		EN	yes
Sapotaceae *Manilkara elata* (Allemão ex Miq.) Monach.	yes		EN	no
Sapotaceae *Pouteria pachycalyx* T. D. Penn.	yes		CR	yes
Sapotaceae *Pradosia kuhlmannii* Toledo	yes	EN	EN	no
Solanaceae *Brugmansia suaveolens* (Willd.) Sweet	no		EW	no
Solanaceae *Brunfelsia jamaicensis* Griseb.	no		VU	no
Urticaceae *Coussapoa curranii* S. F. Blake	yes	EN	VU	no
Zamiaceae *Ceratozamia kuesteriana* Regel	no		CR	no
Zamiaceae *Dioon purpusii* Rose	no		EN	no
Zamiaceae *Encephalartos altensteinii* Lehm.	no		VU	no
Zamiaceae *Zamia pumila* L.	no		VU	no

Apart from the endangered species cataloged by the IUCN [30] and the Brazilian Red List [29], utilizing the BGCI Threat Search tool for reference disclosed that an additional 152 species at risk (CR, EN, and VU), as compiled in the regional lists integrated into this tool, are also being nurtured within this collection (Figure 4). These encompass Brazilian native species facing endangerment in neighboring countries and exotic species that are imperiled in their original habitats. The addition of these species further amplifies the collection's importance, underscored by its ex situ conservation initiatives.

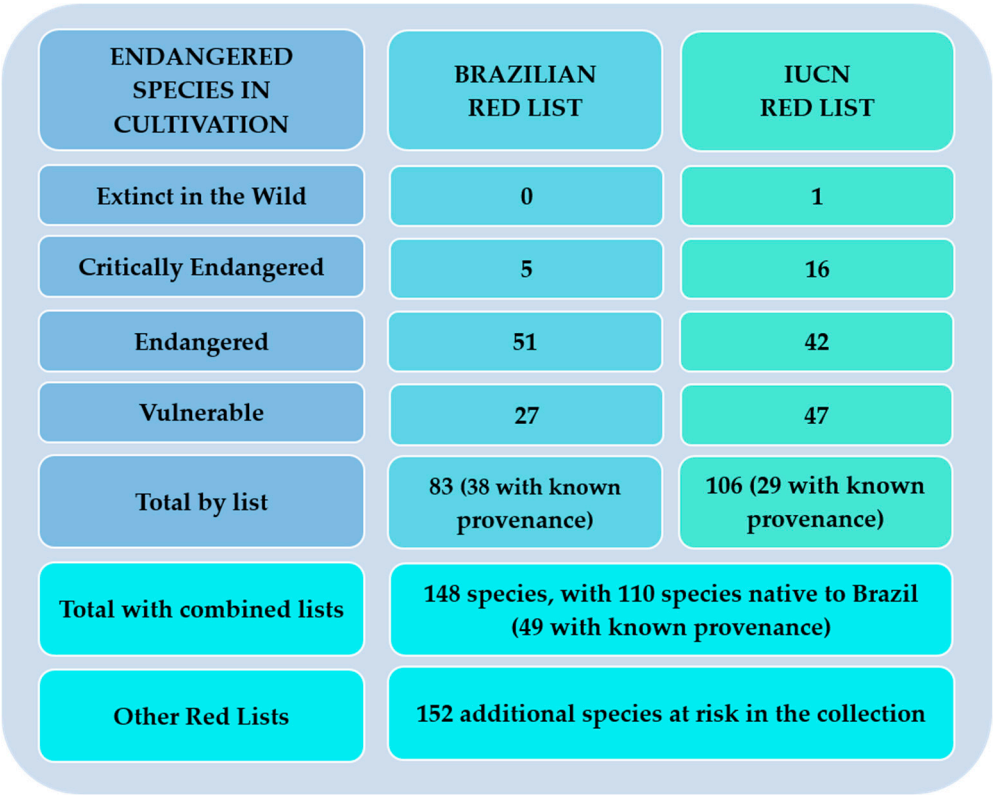

Figure 4. Summary of information on endangered species cultivated in the JBRJ arboretum collection.

4. Discussion

Historical records from 1935 indicated the presence of 5105 identified species in cultivation at the JBRJ [33]; this figure likely included the themed collections as well as information from the arboretum collection. A subsequent inventory conducted between 1999 and 2007 provided insights into the composition of the arboretum collection during that period; this assessment revealed that the collection comprised 7900 specimens, representing 1443 species according to the final inventory report (unpublished data). Plausible explanations for the reduction in the overall count of species currently under cultivation include factors such as synonymization, contribution to diversity from other institutional themed collections, and historical events like the 1936 flood incident [34], along with other contributing factors.

The botanic garden collection was created to acclimatize exotic species in Brazil [36]; therefore, in its inception, these exotic species held significant predominance, but expeditions aimed at increasing native species in cultivation were reported from 1891, even before conservation concerns, as a matter of valuing native flora [16]. The assessment conducted within the collection at the onset of the current century determined that approximately 35% of the species under cultivation were of native origin [22]. In 2015, the institutional policy for living collections made the guideline to prioritize native species over exotic ones official, so there has been a tendency to increase the percentage of native species composition, with the maintenance of exotic species considered of historical or conservation value.

When comparing the JBRJ arboretum collection with other botanic gardens, it can be challenging to make a complete comparison due to the fact that the JBRJ arboretum does not showcase its entire institutional living collection. However, when considering only tree species, JBRJ boasts 809 species across 77 botanical families, with 558 of them being native to Brazil. By contrast, the tree collection at the Royal Botanic Garden Edinburgh comprises 730 species from 56 families [37]. Despite having a higher number of tree species, the diversity of native Brazilian tree species stands at 8268 [8]. As such, the JBRJ arboretum represents 6.75% of Brazilian diversity in terms of tree species.

Recent data from the institution's three most extensive themed collections revealed the following diversity metrics: 413 taxa (species and infraspecies) within the Cacti and Succulents collection in 2022 [38], 480 taxa (species and infraspecies) within the Bromeliad collection in 2022 (unpublished data), and 641 taxa (species and infraspecies), along with over 600 distinct hybrids under cultivation, within the Orchid collection in 2023 (unpublished data). When the arboretum collection is combined with these three thematic collections, a cumulative count of 2954 taxa, excluding hybrids, is realized within the arboretum area. However, this number is anticipated to increase further as diversities from the Ferns, the Shade Collection (Araceae and Marantaceae), Carnivorous Plants, and Medicinal Plants collections, which will be surveyed in the forthcoming years, are added to the count.

The large number of species represented by only one specimen is far from ideal for a collection; since the presence of just one specimen for each species proves insufficient [39], the collection should strive for redundancy to prevent species loss due to the demise of said specimen [40], which is even further from ideal, considering that traditional ex situ conservation guidelines recommend that genetically diverse living collections require 10 to 50 plants from five different populations—a very challenging goal to be achieved in tropical regions [7,41]. Nevertheless, this challenge must be pursued, striking a balance between the constraints posed by space and resources, all while maximizing the number of specimens under cultivation [42].

For unidentified specimens, close monitoring is essential to collect and identify them accurately, as knowing their correct names is crucial for managing botanic garden collections of high conservation value. [43]. Some of the identified specimens do not have a voucher in the herbarium RB; therefore, we have expanded the sampling to encompass specimens already identified within the collection to ensure that, over time, the complete collection will feature deposited vouchers.

The botanical families represented in the collection show notable absences. Families such as Asteraceae, Bromeliaceae, Melastomataceae, Orchidaceae, and Poaceae, which are among the top 10 in terms of diversity in Brazil [44], do not appear in the arboretum cultivation ranking (Table 1); among these, Bromeliaceae and Orchidaceae have their themed collection within the institution and, consequently, were not included in the arboretum dataset, whereas Asteraceae and Poaceae are mainly herbaceous and bushy [8]—habits not very abundant in the arboretum. Furthermore, the institutional themed collection of Medicinal Plants houses a significant number of Asteraceae species in its inventory; these data were also not included in the arboretum dataset.

Historically, regarding the arrangement of species into planting beds, aside from organizing based on their botanical families, specific areas were also designated to represent distinct Brazilian phytogeographic domains. This initiative led to the establishment, between 1920 and 1935, of sections dedicated to the Amazon region (comprising 31 beds across six different sections), the Caatinga (with 2 beds in one section), and the Cerrado (occupying 1 bed) [45,46]. In a more recent development, in 1980, two planting beds were allocated for cultivating Restinga species, a coastal vegetation type within the Atlantic Forest, which houses numerous endangered species [47] (Figure 2).

In the present time, the Caatinga region, once characterized by a prevalence of xerophytic species, is absent from the arboretum. It is understood that the first cacti cultivated at JBRJ were initially established there and subsequently relocated to the institutional Cactarium, which was established in 1934 [34]. Furthermore, it is probable that various other species faced difficulties while adjusting to the climate of Rio de Janeiro, which significantly contrasts with that of the Caatinga region.

Concerning the conservation of native species, the first report of an imperiled species cultivated in the arboretum dates back to 1916; at the time, "ipecacuanha" (*Carapichea ipecacuanha* (Brot.) L. Andersson), a species with medicinal attributes, was exploited and already classified as endangered [48]. Presently, this species retains its vulnerable status according to the Brazilian Red List [29], yet regrettably, it is no longer under cultivation. The

Global Plant Conservation Strategy establishes in Target 8 that at least 75% of threatened plant species should be present in ex situ collections, preferably within their country of origin [25]. Considering that the Brazilian Red List comprises 3209 plant species [29], the contribution of the arboretum's living collection towards achieving this target stands at 2.59%; it is important to note that this is not the entirety of JBRJ's contribution, as the other themed collections of living plants are not included in this total.

Botanic gardens serve a major role in species preservation, not only by cultivating endangered plants but also by implementing integrated conservation measures [6]. To fully embrace this responsibility, it is essential to undertake actions focused on reintroducing species into their natural habitats, a task performed in a very preliminary manner by this collection.

Having exotic species in our collection is a valuable addition, not only because of their historical significance but also due to their conservation value, especially for endangered species from other countries [31]. However, it is important to acknowledge the responsibility that comes with it and take necessary measures to prevent them from becoming invasive. This is especially important because our arboretum is adjacent to a protected forest area, which is a part of the JBRJ area and neighbors Tijuca National Park, the largest urban forest in the world. We must learn from the past, such as in the case with the jackfruit trees that became invasive in this forest many decades ago [49], and take necessary precautions to ensure that our collection does not pose a threat to the ecosystem.

In 2021, JABOT introduced a new module for including phenology data. Moving forward, it would be desirable to also include photographs and vouchers for all the specimens so that our collection can be better curated [50]. This will allow us to extract the maximum amount of information from our specimens while they are in our care [43]. Our team will continue to search for provenance data in institutional historical documents, as this is a constant task that helps increase the value of our collections.

The arboretum's living collection currently lacks any registered bryophytes. At JBRJ, while studies regarding this group have been conducted on the spontaneous occurrence of species in the arboretum, including samples deposited in the institutional herbarium collection (RB) [51], these species are not recorded nor cultivated in the collection. Antonelli et al. [4] emphasize the underrepresentation of bryophytes within living collections; this reality is also encountered here, and as steps for the future, it would be interesting to assess the possibilities of incorporating this diversity into the collection through some of the potential methods for conserving this group [52,53]. Formally incorporating these bryophytes into the collection would also ensure their availability for research and educational endeavors conducted within the botanic garden.

Another crucial step towards advancing ex situ conservation work at JBRJ is to calculate the conservation value of the specimens in cultivation by assessing factors related to their extinction risk, such as the likelihood of their extinction in the wild, the extent of representation of the species in ex situ collections, and vulnerability to predicted threats [12]. This assessment will enable the team to evaluate plant maintenance, future additions, and collection management. In order to make informed decisions about the best care and growth of the collection, it is imperative to have a clear understanding of the value of each specimen.

It is essential to have a wide range of diverse living collections in cultivation, not just for species conservation but also for research purposes. As the Arnold Arboretum [54] points out, while seed banks and germplasm repositories can help preserve threatened species, only living accessions of these taxa can be studied to understand their biology. This highlights the importance of maintaining living collections to study and gain insights into the natural world.

5. Conclusions

Although the numbers show that there is still much work to be done, it is encouraging to see that the institution is moving in the right direction for the ex situ conservation

of the Brazilian flora. There is certainly much room for improvement, both in terms of species diversity and the genetic variability of those to be conserved. The assessment of the collection is the first step in knowing where efforts should be optimized in favor of conservation. To achieve more favorable results, the joint effort of the Brazilian botanic gardens will be paramount.

As collection managers and growers, it is crucial to understand the importance of maximizing the value of the collections in our care. By doing so, we can contribute greatly to the conservation of species. This means taking great care to preserve and maintain the collections, as well as share them with others who can benefit from their value. Together, we can ensure that these species are protected and can continue to thrive for generations to come. By taking action now, we can improve the ex situ conservation efforts of this collection and benefit the national flora.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/jzbg5030026/s1, Table S1—Inventory list of species and hybrids cultivated in the Rio de Janeiro Botanical Garden arboretum collection between January and July 2023.

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