BRAZILIAN BOTANIC GARDENS: AN ASSESSMENT OF CONSERVATION CAPACITY

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ABSTRACT

We argue that botanic gardens, as plant conservation focused institutions, have been tested in temperate regions that possess a relatively robust conservation infrastructure and a relatively low number of threatened species. The ability of the Brazilian botanic gardens to support plant conservation is especially challenging, given their small number relative to Brazil's plant diversity and the increasing rate of habitat loss and plant endangerment. This study, the first for Brazil, assesses the conservation capacity of Brazilian botanic gardens. An assessment is made of the status of conservation facilities in Brazilian botanic gardens and the conservation status of their plant collections. This was based on a survey sent to thirty-six Brazilian botanic gardens in 2011– 2013 using information from the 2008 Brazilian Red List, and seven state conservation lists. The results identified a small percentage of threatened species (n =102/21 per cent) in *ex situ* collections of 22 botanic gardens and less than 10 per cent representation for each state red list. An assessment based on the updated Brazilian Red List (2014) showed that 425 threatened species were maintained in living collections of 18 botanic gardens. Despite the extensive size of some collections, the proportion of threatened species in the collections was found to be very low. Improvement in infrastructure, technical capacity, including horticultural skills, and development of policies and protocols will be necessary to increase the effectiveness of the collections for conservation aims.

INTRODUCTION

In recent years botanic gardens have increasingly adopted a strong conservation mission with a commitment to multidisciplinary scientific research that directly supports conservation (Donaldson, 2009). Similarly, botanic gardens have strengthened their activities for outreach and public education. Importantly, with about 200 million people visiting botanic gardens each year, they are uniquely placed to showcase environmental issues and raise public awareness about biodiversity loss (Maunder *et al.*, 2004; Willison, 2006).

Botanic gardens directly contribute to the Global Strategy for Plant Conservation (GSPC) (Wyse Jackson & Kennedy, 2009); GSPC Target 8 suggests that for signatory nations at least 75 per cent of threatened plant species should be held in *ex situ* collec-

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tions and at least 20 per cent available for recovery and restoration programmes (UNEP, 2010).

However, there is a lack of monitoring mechanisms to assess the implementation of these guidelines, especially the GSPC targets (Paton & Lughadha, 2011). In Brazil, there are no assessments on the performance of the botanic gardens regarding their contribution to the conservation of native flora. This paper identifies the current status of plant conservation activities and the steps needed to improve effectiveness.

The context for botanic-garden-based plant conservation in Brazil

Brazil is a huge country (8,515,767km^2) with a diverse flora (IBGE, 2012); the number of endemic vascular plants (56 per cent) is the highest amongst the neotropical countries, while the absolute number of endemics (18,082) is higher than any other country (Forzza *et al.*, 2012). Brazil holds two Biodiversity Hotspots: the Atlantic Forest and the Cerrado (Mittermeier *et al.*, 2004). Both areas are highly threatened by agricultural expansion and deforestation, the two main drivers of biodiversity loss in the country (Brazil Ministry of the Environment, 2010).

Brazil has 36 botanic gardens, situated in 17 states with a concentration in the south-east and southern regions (RBJB, 2010). The majority of these are located in the Atlantic Forest biome, the most densely populated part of Brazil. The small number of botanic gardens in the Amazon biome (three) contrasts with that biome's huge size, almost 50 per cent of Brazil's land area, and biological diversity. Similarly, the Cerrado, considered the most diverse tropical savanna in the world (MMA, 2007), has four botanic gardens. Additionally, there are no botanic gardens in the vegetation formations of Pantanal, Pampa and Caatinga biomes. The 36 botanic gardens vary greatly in age, structure, resources and administration. They possess a wide range of administrative affiliations, such as ministries, environmental secretariats and universities, and include both the public and private sectors. In 1991, coordinated by the Brazilian Network of Botanic Gardens (RBJB), they developed an Action Plan with a strong commitment to the conservation of threatened plant species (Pereira *et al.*, 2004).

As a megadiversity country, Brazil has particular challenges for plant conservation. Historically, plant conservation assessments have underestimated the number of threatened plant species in Brazil (Moraes *et al.*, 2014). However, significant advances have been made in recent years. The Brazilian Red List (2008–2014) identified 472 nationally threatened plant species but no system of risk categories was assigned to these species (Brasil Ministério do Meio Ambiente, 2008). The updated Brazilian List of Threatened Species (Brasil Ministério do Meio Ambiente, 2014), using the IUCN Categories of Threat (IUCN, 2001), identified 2,113 species. This list was based on the evaluation of 4,617 plant species by the National Centre for Flora Conservation (CNCFlora) at Instituto de Pesquisas Jardim Botânico do Rio de Janeiro (JBRJ) (Martinelli & Moraes, 2013). The Atlantic Forest, the most deforested Brazilian biome, was represented with the largest number of threatened species that are also endemics to

the biome (n=1,155/55 per cent) followed by the Cerrado (n=493/23 per cent) (Brasil Ministério do Meio Ambiente, 2014). In addition, the states of Santa Catarina, Paraná, Minas Gerais, Rio Grande do Sul, Pará, São Paulo and Espírito Santo have developed their own red lists, with each state adopting a different system for conservation evaluation (Moraes *et al*., 2014).

METHODOLOGY

The survey and questionnaire were sent to 36 botanic gardens between 2011 and 2012 (Table 1 & Fig. 1) in order to assess the diversity and utility of existing plant collections. It contained closed and open-ended questions about the number of threatened plant species held in *ex situ* collections, their taxonomic verification, the number of accessions and specimens, the collection data and their use in research and environmental education programmes. It also included aspects of the collection's management, such as curation, conservation protocols and record keeping. The former Brazilian Red List (hereinafter referred as the 2008 Red List) provided the taxonomic basis for this primary analysis. Scientific names provided by the botanic gardens had been updated according to the Brazilian Flora List (BFG, 2015; Prado *et al.*, 2015).

Those botanic gardens located in the seven states which had issued their own state red lists were also asked to report the species from these lists in their collections. The seven state red lists used as a reference for the inventory were Santa Catarina (Klein, 1990), Paraná (Hatschbach & Ziller, 1996), Minas Gerais (COPAM, 1997), Rio Grande do Sul (Rio Grande do Sul, 2003), Pará (COEMA, 2007), São Paulo (São Paulo, 2004) and Espírito Santo (Espírito Santo, 2005).

Visits were made to botanic gardens in São Paulo and Espírito Santo states. The assessment of data concerning the *ex situ* species kept in JBRJ, Jardim Botânico de São Paulo (JBSP), Museu Mello Leitão (MBML) and Jardim Botânico Plantarum (JBP) was performed directly from the collections' digital files, which had been made available for this research.

Following the updated Brazilian Red List (hereinafter referred as the 2014 Red List) (Brasil Ministério do Meio Ambiente, 2014), an additional survey of threatened species in *ex situ* collections was undertaken for the 26 botanic gardens which participated in the study.

RESULTS

Botanic gardens and collections management

Out of thirty-six botanic gardens contacted, four were new (post 2005) and two were restructuring their collections. These six botanic gardens were unable to contribute to the survey. In addition, four botanic gardens did not answer the survey. Thus, 26 out of 36 (70 per cent) institutions were incorporated into the analysis (Table 1). Information

No.	Botanic garden (Abbreviation)	City/State	Year founded	Aff.
1	Instituto de Pesquisas Jardim Botânico do Rio de Janeiro (JBRJ)	Rio de Janeiro/RJ	1808	F
2	Bosque Rodrigues Alves (BRA)*	Belém/PA	1883	M
3	Museu Paraense Emílio Goeldi (MG)	Belém/PA	1895[a]	F
4	Horto Botânico do Museu Nacional (HMN)**	Rio de Janeiro/RJ	1896	F
5	Jardim Botânico de São Paulo (JBSP)	São Paulo/SP	1928	S
6	Parque Zoobotânico Orquidario de Santos (PZOS)**	Santos/SP	1945	M
7	Museu de Biologia Prof. Mello Leitão (MBML)	Santa Teresa/ES	1949	F
8	Jardim Botânico da Fundação Zoobotânica do Rio Grande do Sul (FZBRS)	Porto Alegre/RS	1958	S
9	Museu de História Natural e Jardim Botânico da UFMG (MHNJB)	Belo Horizonte/MG	1968	F
10	Jardim Botânico do Instituto de Botânica – UNESP (JBUNESP)	Botucatu/SP	1974	S
11	Jardim Botânico Amália Hermano Teixeira (JBGO)	Goiânia/GO	1978	M
12	Jardim Botânico do Recife (JBR)	Recife/PE	1979	M
13	Jardim Botânico da Universidade F Rural do Rio de Janeiro (JBUFFRJ)	Seropédica/RJ	1980	F
14	Jardim Botânico da Universidade Federal de Santa Maria (JBUFSM)	Santa Maria/RS	1981	F
15	Jardim Botânico de Brasília (JBB)	Brasília/DF	1985	D
16	Jardim Botânico da Fundação Zoobotânica de Belo Horizonte (FZBBH)	Belo Horizonte/MG	1991	M
17	Jardim Botânico Municipal Francisca Maria Garfunkel Rischbieter (JBFMGR)	Curitiba/PR	1991	M
18	Jardim Botânico de Pipa (JBPI) *	Tibau do Sul/RN	1991	P
19	Jardim Botânico de Caxias do Sul (JBCS)	Caxias do Sul/RS	1992	M
20	Jardim Botânico Municipal de Paulínia Adelelmo Piva Júnior (JBMP)	Paulínia/SP	1992	M
21	Jardim Botânico Municipal de Bauru (JBMB)	Bauru/SP	1994	M
22	Jardim Botânico Municipal de Santos Chico Mendes (JBMSCM)	Santos/SP	1994	M
23	Jardim Botânico de Lajeado (JBL)	Lajeado/RS	1995	M
24	Jardim Botânico do Instituto Agronômico de Campinas (JBIAC)	Campinas SP	1998 [b]	S
25	Jardim Botânico de João Pessoa Benjamim Maranhão (JBBM)	João Pessoa/PB	2000	S
26	Jardim Botânico Adolpho Ducke de Manaus (JBAD) *	Manaus/AM	2000	M
27	Jardim Botânico de Salvador (JBSSA)	Salvador/BA	2002	M
28	Fundação Jardim Botânico de Poços de Caldas (FJBPC)	Poços de Caldas/MG	2003	M
29	Jardim Botânico de Jundiaí (JBJ)	Jundiaí/SP	2004	M
30	Jardim Botânico de Mato Grosso (JBMT) **	Cuiabá MT	2005	S
31	Jardim Botânico de Londrina (JBLO) **	Londrina/PR	2006	S
32	Jardim Botânico da Univille (JBUNIVILLE)	Joinville/SC	2007	P
33	Jardim Botânico Plantarum (JBP)	Nova Odessa/SP	2007	P
34	Jardim Botânico de Sorocaba (JBS) **	Sorocaba/SP	2010	M
35	Jardim Botânico Faxinal do Céu (JBFC) **	Pinhão/PR	2010	P
36	Jardim Botânico Inhotim (JBI) *	Brumadinho/MG	2010	P

* Did not answer the survey.
** New institutions or institutions that were restructuring their collections.
[a] Zoobotanic Park founded; [b] Institution assumed botanic garden functions.

Table 1 List of Brazilian botanic gardens. Aff. (Affiliation) – F (federal); M (municipal); S (state); D (district); P (private).

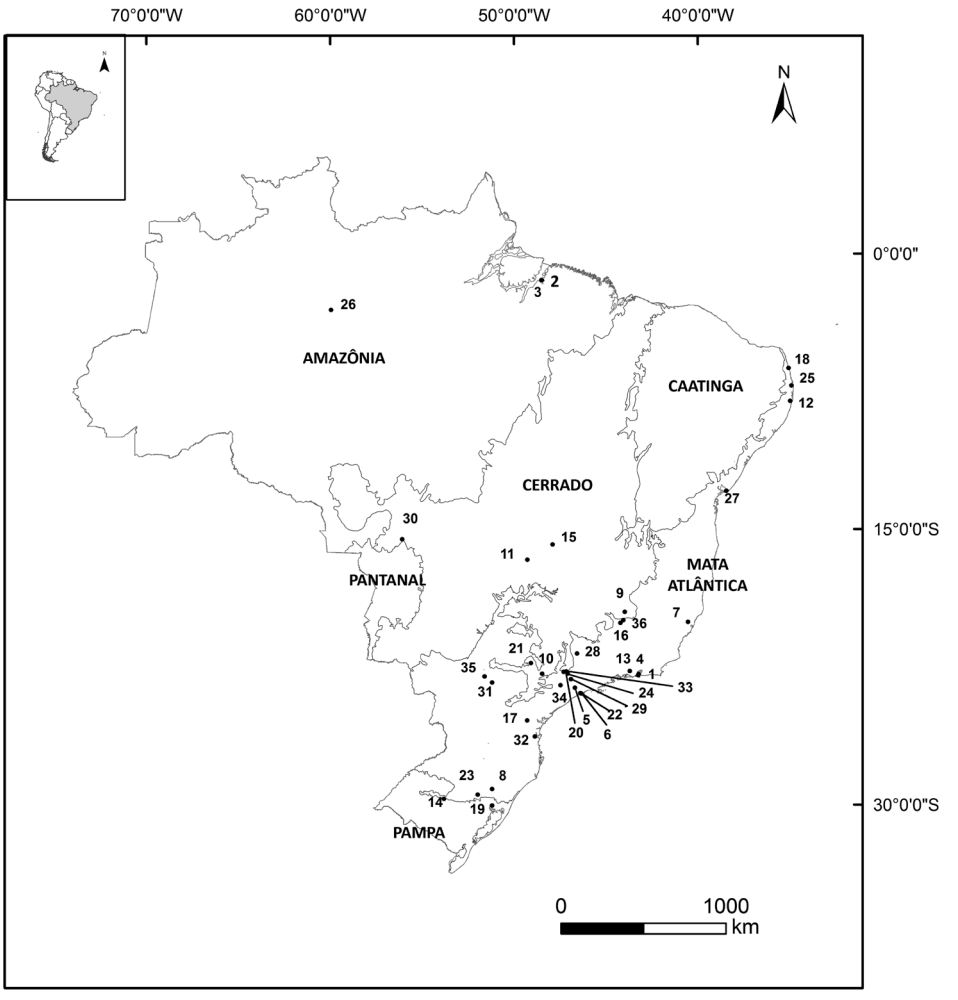

Fig. 1 Geographic distribution of Brazilian botanic gardens by biome. The numbering of the map corresponds to the listing in Table 1.

consolidated from the questionnaires regarding general aspects of botanic gardens and the management of *ex situ* collections is presented in Table 2.

Threatened species in ex situ *collections – 2008 Red List and state lists*

The *ex situ* collections assessment recorded 102 out of 472 (21 per cent) threatened species from the 2008 Red List and 223 out of 3,503 (6 per cent) species from the states lists, including accessions in seed banks, *in vitro* and in living collections (Table 3). These species were maintained in twenty-two (85 per cent) botanic gardens; four botanic gardens held no samples of threatened species in *ex situ* collections. The botanic

Aspects of botanic gardens (BGs) and collections		
Total area of BG (ha)	**BGs**	**(n=26)**
1 to 50	16	(62%)
51 to 100	3	(12%)
101 to 300	2	(8%)
301 to 500	3	(12%)
Over 500	2	(8%)
Area of natural vegetation (%)	**BGs**	**(n=26)**
No natural vegetation	7	(27%)
Up to 50% of BG's total area	7	(27%)
Over 50% of BG´s total area	12	(46%)
Area of collections (%)	**BGs**	**(n=26)**
Up to 50% of BG´s total area	17	(65%)
Over 50% of BG´s total area	9	(35%)
Employees working with collections*	**BGs**	**(n=26)**
1 to 10	8	(31%)
11 to 20	8	(31%)
21 to 40	6	(23%)
41 to 60	3	(12%)
61 to 100	–	–
101 to 200	1	(4%)
Collection management	**BGs**	**(n=26)**
Curator	21	(81%)
Collection policies	3	(12%)
Management plan	2	(8%)
Collecting guidelines	7	(27%)
Expeditions to collect botanic material	20	(77%)
Types of collections	**Collections**	**(n=130)**
Seed collections	2	(1,5%)
In vitro collections	3	(2,5%)
Living collections	125	(96 %)
Data management of collections	**Collections**	**(n=130)**
No records systems	9	(7%)
Manual records	16	(12%)
Digital records	105	(81%)
Percentage of digitisation		**(n=105)**
Collections fully digitised		(66%)
Collections partially digitised (50 a 99%)		(27%)
Not informed		(8%)

* These numbers include technical staff and employees involved with the horticultural maintenance of the garden area.

Table 2 General characteristics of Brazilian botanic gardens and *ex situ* collections management.

garden living collections held the greatest diversity of threatened species (99 per cent of all taxa).

There were two botanic gardens with active seed banks: JBRJ with three species from the 2008 Red List and Jardim Botânico da Fundação Zoobotânica do Rio Grande do Sul (FZBRS) with six species from the Rio Grande do Sul state red list. Only two species were held exclusively in seed banks and the remaining seven species were represented in both seed banks and living collections.

Three botanic gardens (FZBRS, JBSP and Jardim Botânico de Brasília (JBB)) maintained nineteen threatened species *in vitro* culture; eighteen of these were also represented in the living collections. Sixteen of these species are Orchidaceae, with only two species duplicated in two botanic gardens.

Concerning the living collections, the assessment recorded 102 species from the 2008 Red List in 22 botanic gardens. Fifteen botanic gardens maintained 220 species from their state red lists. The proportion of species per state list held in collections was low, corresponding to less than 10 per cent of each list (Table 4). The percentage of species from the Critically Endangered category in collections of four state lists was as follows: 18 per cent (Rio Grande do Sul), 8 per cent (São Paulo), 2 per cent (Minas Gerais) and 1.5 per cent (Espírito Santo).

Collection types	2008 Red List	State lists*	Total
Ex situ collections	102	223	325
Seed bank	3	6	9
In vitro	9	10	19
Living collection	102	220	322

* The numbers exclude species also in the 2008 Red List.

Table 3 Number of threatened species in different *ex situ* collections types according to the 2008 Red List (Brasil Ministério do Meio Ambiente, 2008) and state red lists.

State lists	Species in collections (% of state list)	BGs
São Paulo (SP)	92 (8%)	7
Rio Grande do Sul (RS)	56 (9%)	4
Minas Gerais (MG)	23 (4%)	1
Espírito Santo (ES)	23 (3%)	1
Paraná (PR)	26 (5%)	1
Pará (PA)	2 (3%)	1
Santa Catarina (SC)	0	0

Table 4 Representation of threatened species from the state red lists held in living collections and respective number of botanic gardens (BGs).

The representation of the 102 threatened species in each botanic garden varied significantly between gardens; while one botanic garden maintained 57 threatened species in its living collections, 16 botanic gardens held fewer than 10 species (Fig. 2). The distribution of species in botanic gardens was also uneven. It was observed that a relatively large number of taxa (54/53 per cent) were held in only one institution, while a range of one to three species were recorded for more than five botanic gardens (Fig. 3). JBRJ had the highest number of unique taxa (23).

The 102 threatened species in living collections were represented by 25 families and 62 genera. The best-represented families were Bromeliaceae (30), Orchidaceae (15) and Cactaceae (10). These families were also the most frequent in the 2008 Red List. The species were represented by 345 accessions and a total of 1,697 plants in the collections (mean of 4.91 plants per accession). An accession is considered to be material or a group of material with the same provenance data (same species, collected in the same place, on the same date and by the same collector). This equates to a mean number of three accessions and sixteen individuals per taxa. However, the number of accessions and individuals varied greatly among the species; a large number of species (n=37/36 per cent) were represented by only one individual in cultivation (e.g. one species with one accession comprising one individual). Some species, for example *Ocotea porosa* (Lauraceae), were represented by a large number of accessions (20) and a relatively low number of individuals (38), indicating

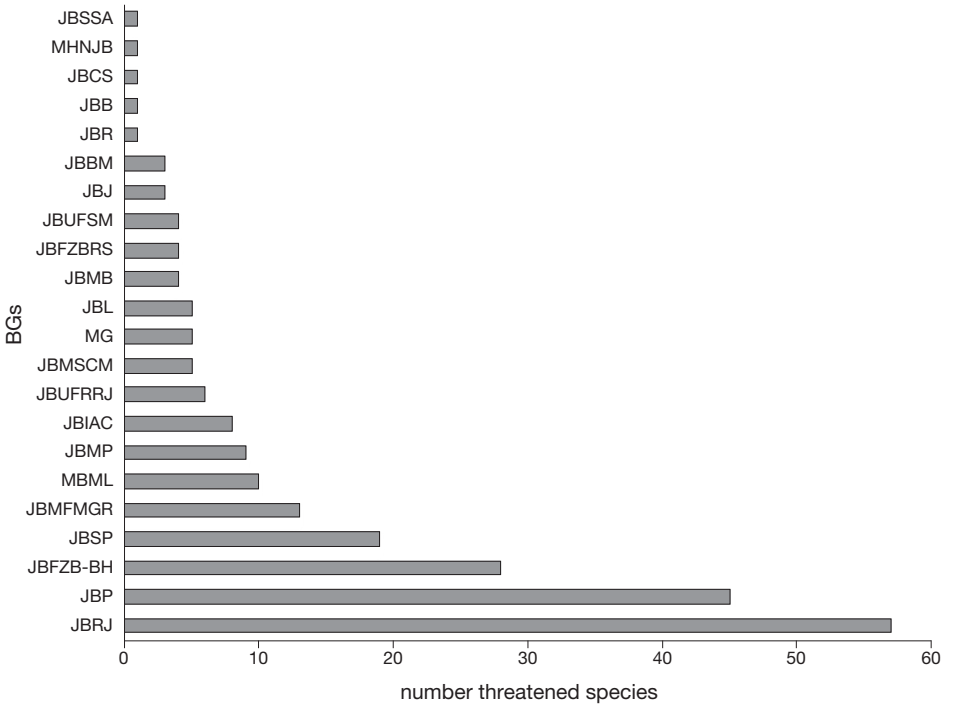

Fig. 2 Number of threatened species from the 2008 Red List in each botanic garden.

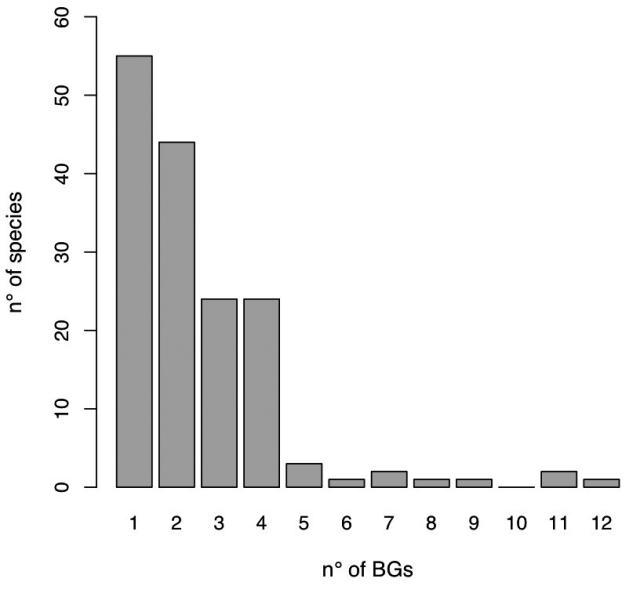

Fig. 3 Distribution of threatened species from the 2008 Red List in botanic gardens.

a low average of individuals per accession. On the other hand, some species had a higher level of representation, for instance *Caesalpinia echinata*, pau-brasil (Fabaceae) (12 accessions and 195 specimens) and *Euterpe edulis*, palmito (Arecaceae) (17 accessions and 225 specimens), both considered to be flagship species for conservation.

Complete accession records (information concerning provenance, collector, date and locality of collection) were recorded for 132 out of 345 (38 per cent) accessions from 50 out of 102 (49 per cent) species. For the remaining 213 accessions, one or more parts of the plant record were missing (Table 5). Of the 345 accessions representing 102 taxa, 49 per cent are of wild provenance, 50 per cent have a known locality, 51 per cent have a known collector and 36 per cent are taxonomically verified.

Threatened species – use for study and environmental education

Thirteen botanic gardens (50 per cent) recorded undertaking environmental education actions with a focus on threatened species. Eight botanic gardens (31 per cent) recorded carrying out research on threatened species from the 2008 Red List. The two most cited studies were on cultivation (ten species) and phenology (nine species). Reintroduction work was recorded for six species, including the project with *Tillandsia linearis* (Bromeliaceae) carried out by JBSP. Reproductive biology (four species) and genetic studies (one species) were also mentioned, but to a small degree. *Dimorphandra wilsonii* (Fabaceae) was the object of a larger number of studies (six) under the coordination of the Jardim Botânico da Fundação Zoobotânica de Belo Horizonte (FZBBH).

Accession data	Number of accessions (n=345)
Provenance	
Wild provenance	171 (49%)
No wild provenance	26 (8%)
Unknown or answer not provided	148 (43%)
Locality	
Known state and locality	173 (50%)
Known state	11 (3%)
Unknown or answer not provided	161 (47%)
Date of collection	
From 1951 to 1992	42 (12%)
From 1993 to 2012	110 (32%)
Unknown or answer not provided	193 (56%)
Collector	
Known collector	177 (51%)
Unknown or answer not provided	168 (49%)
Verification	
Taxonomically verified	125 (36%)
No verified	48 (14%)
Unknown or answer not provided	172 (50%)

Table 5 Record keeping of accessions data from the 102 threatened species kept in living collections of 22 botanic gardens.

Assessing the 2014 Red List

The publication of the 2014 Red List (2,113 species) resulted in a significant increase in the number of Brazilian species officially classified as threatened. The additional survey received data from 18 botanic gardens. The survey identified 425 out of 2,113 (20 per cent) threatened species in living collections. The percentage of species from the current Red List in living collections was very similar to that from the 2008 Red List (21 per cent).

The proportion of the 425 species recorded in each risk category from the 2014 Red List, with the largest number of Endangered species (224/53 per cent) followed by Vulnerable (123/29 per cent) and Critically Endangered (76/18 per cent), was similar in ratio to the 2014 Red List (EN= 1142/54 per cent; VU= 495/23 per cent; CR= 467/22 per cent) (Fig. 4).

Concerning the distribution of species in botanic gardens, 254 (60 per cent) species were maintained by one botanic garden (Table 6), while four species were the most frequent among them: *Caesalpinia echinata* and *Euterpe edulis* (12 gardens); *Swietenia macrophylla* (11 gardens) and *Dalbergia nigra* (10 gardens).

Asteraceae, the largest plant family listed in the 2014 Red List, with 239 species, has only one species represented in cultivation. Bromeliaceae, the second largest family in the 2014 Red List, had the highest representation of threatened species in botanic

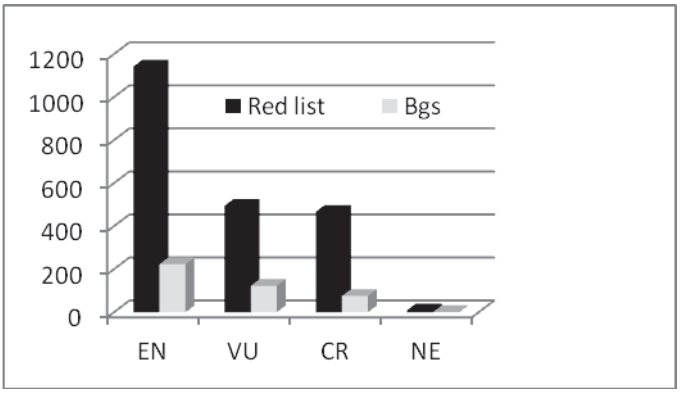

Fig. 4 Proportion of threatened species from 2014 Red List in the living collections of 18 botanic gardens according to the categories of threat (IUCN, 2001).

Botanic gardens	CR	EN	VU	NE	Total
1	55	136	62	1	254 (60%)
2 to 5	19	84	51	1	155 (36%)
6 to 9	2	3	7	0	12 (3%)
10 to 12	0	1	3	0	4 (1%)
Total	76	224	123	2	425

Table 6 Distribution of threatened species from the 2014 Red List in 18 botanic gardens according to the category of threat (IUCN, 2001).

garden collections (Table 7), with the largest number of species in the JBRJ. The largest collection of threatened Orchidaceae was maintained by JBSP.

From the 425 threatened species in collections, 51 (12 per cent) were recorded as having been collected in areas of natural vegetation of 11 botanic gardens according to the assessment of herbarium records of CNCFlora's database and on existing plant inventories of these reserves (Costa *et al.*, unpublished). Among this group only one species is categorised as Critically Endangered, while twenty-six (51 per cent) are classified as Endangered and twenty-four (47 per cent) as Vulnerable. Most of the species (n=38/75 per cent) have collecting records in just a single reserve. *Euterpe edulis* (Arecaceae) was the species with records for the largest number of reserves (five).

DISCUSSION

General aspects of Brazilian ex situ *collections*

The small area of some Brazilian botanic gardens (six gardens with less than 10ha) and their location in urban centres restricts opportunities for new collection development but

Family	Brazilian Flora*	2014 Red List	Botanic gardens (%)
Bromeliaceae	1,347	202	136 (67%)
Orchidaceae	2,495	168	66 (39%)
Cactaceae	261	76	45 (59%)
Gesneriaceae	212	33	20 (61%)
Amaryllidaceae	135	29	19 (66%)
Arecaceae	283	18	18 (100%)
Fabaceae	2,803	87	12 (14%)

*http://floradobrasil.jbrj.gov.br/reflora/listaBrasil (accessed May 2016)

Table 7 List of the most frequent families with threatened species in living collections of 18 botanic gardens and the respective number of species described for Brazilian Flora.

opens the door to important public outreach activities. However, the majority (73 per cent) of Brazilian botanic gardens have areas of natural vegetation inside their boundaries. These reserves enable the development of conservation initiatives based around *in situ* population management and habitat restoration.

It was observed that some plant collections, mainly those maintained by the historic botanic gardens, hold a large number of exotic species that do not necessarily relate to conservation needs. We recognise that exotic species can have value for public display and public education. However, we also observe that some of the Brazilian botanic garden collections have evolved opportunistically over time without a strong collection strategy to guide their development. Accordingly, current management is faced with the difficult challenge of refocusing collections to meet national conservation needs often within the context of a historic botanic garden landscape.

The lack of strategy documents for the management of collections was a key issue identified by this study. Only three out of twenty-six botanic gardens have developed a written collection policy. This is an essential tool to ensure the establishment of collections that serve the institutional mission (Leadlay & Greene, 1998; Hohn, 2004). Issues such as the purpose of the collection, criteria for acquisition, ethical and legal consideration in collecting, record system and criteria for deaccessioning should be addressed to direct the management of the collections (Donnelly & William, 1990).

Seed banking is considered to be the most effective approach for storing genetically representative samples for long periods in a relatively small space (Walters, 2004; Offord & Meagher, 2009). This approach has proved successful for temperate floras, but historically has not been seen as fully relevant to tropical collections with large numbers of recalcitrant species. This resource has not been adopted on a large scale by Brazilian botanic gardens. Only two active seed banks were recorded and only a small number of threatened species (nine) were being stored.

However, research is showing the increased relevance of cryopreservation and *in vitro* storage techniques for tropical floras (Pillati *et al*., 2011; Pence, 2013; Raven &

Havens, 2014). Cryopreservation has been suggested as an appropriate technique for the long-term storage of germplasm of recalcitrant species (Walters *et al.*, 2013) but experimental research is required to identify the most appropriate material (seeds, embryonic axis, other plant tissues) and protocols for each species (Pammenter & Berjak, 2014). The adoption of this potentially valuable technique is still in an incipient stage among the Brazilian botanic gardens, with some experimentation being undertaken at the JBRJ (Pereira, 2009).

The *in vitro* culture of threatened plants is only practised by three botanic gardens. The cost and specialised requirements in terms of infrastructure, personnel and equipment have limited the use of this technique. Micropropagation has been identified as valuable for the propagation and conservation of some species, such as those with low seed production and others with difficulties concerning reproduction (Bunn *et al.*, 2011). The JBSP, for example, has been investing in research focusing on *in vitro* germination and growth of some orchids threatened by over-exploitation that exhibit low rates of seed germination (Suzuki *et al.*, 2009; Suzuki *et al*., 2010; Schneiders *et al.*, 2012).

Threatened species in collections – quantitative and qualitative aspects

Despite the extensive size of some collections, the proportion of threatened species in the collections was found to be very low. The percentage of species from the current National Red List (20 per cent) held in living collections is well short of the 75 per cent stipulated by GSPC Target 8. Similar assessments, mainly for temperate regions, showed more promising results in terms of percentages of species in *ex situ* collections (Table 8). However, the difficulty of achieving this goal is shared with other tropical countries. The fulfilment of Target 8 has been moderate, especially in the Latin American and Caribbean region (Faggi *et al.*, 2012). The imbalance between the plant diversity and distribution of botanic gardens in the northern and southern hemispheres imposes major challenges for the tropical botanic gardens regarding the delivery of the GSPC (Chen *et al.*, 2009). We suggest that Target 8 is an unfeasible goal for some megadiverse countries, such as Brazil, where the scale of loss dictates a conservation strategy that focuses on *in situ* conservation. Moreover, the advance on the evaluation of the conservation status of the native flora will certainly increase the listings of threatened species and consequently the challenge of conserving them.

The uneven distribution of threatened species among the Brazilian botanic gardens followed the same pattern described in other studies. A large number of threatened species (n=254/60 per cent) were held in only one botanic garden. The assessment of European collections indicated a significant percentage (43 per cent) of threatened taxa in only a single collection (Sharrock & Jones, 2011), as well as the inventory of Mexican botanic gardens that recorded 33.5 per cent of species limited to just one garden (Caballero, 2013). For North America, nearly half of all endangered taxa in collections were recorded from one collection (Hird & Kramer, 2013). In South Africa, 64 per cent of the Red List species are confined to one collection (SANBI, 2006).

Continent/Country	Species in collections	Source
Brazil	20%	This study
Europe	42%	Sharrock and Jones, 2011
North America	39%	Kramer *et al.*, 2011
Mexico	45%	Caballero, 2013
Australia and New Zealand	56%	Sharrock *et al.*, 2014

Table 8 Some regional and national assessments of threatened species in *ex situ* collections.

This raises concerns about the security of these species in cultivation, since the collections are subject to stochastic events, such as disease, fire, theft and severe weather conditions (Maunder *et al*., 2001b). Moreover, given the large proportion of species represented by only one individual in Brazilian collections we can assume the absence of intraspecific genetic diversity sampling compromising the quality of the collection and indicating potential problems for the sexual reproduction of the dioecious species or those with self-incompatibility. In addition, collections can suffer significant declines in diversity when collections change curator or horticulturist and the level of horticultural investment drops.

This study showed that the majority of the Brazilian botanic gardens were not adopting standard protocols to guide the collection of biological material. Sampling protocols are essential in guiding the establishment of a genetically representative collection (Havens *et al.*, 2004). Despite the unknown origin of some accessions, the great proportion of accessions (48 per cent) from wild origin is a positive characteristic of the Brazilian collections.

The management of collection data needs to be improved by Brazilian botanic gardens. The maintenance of all these data and those accumulated during the life of the plant add significant value and importance to the collection (Leadlay & Greene, 1998). A national plant record system, other than the Excel software, which has been largely adopted by many botanic gardens, is an urgent requirement. A database to integrate the diverse collections of the institution and provide quick access to the information associated with the species and specimens is an essential tool to optimise the management and monitoring of the collections over time. It is also very relevant to ensuring the long-term security of data.

Monitoring and evaluating the collections (Aplin, 2008; Bedini & Carta, 2010; Sutherland & Cosgrove, 2010; Rae, 2011) is an urgent issue. These processes are essential to guide the curation of the collections and improve their utility for conservation purposes. The quality of horticultural skills and curatorial activities can have a great influence on the dynamics of the collection (Maunder *et al.*, 2001b). Accordingly, the periodic review of the collection over time is an important step to improve collection management. The analysis of trends in collections, for example, led to the establishment of targets to increase the wild origin percentage of accessions at the Royal Botanic

Garden Edinburgh (Rae, 2011). In some cases the evaluation shows the shocking reality that large parts of the collection have limited value to research or conservation (Aplin, 2008).

Use of collections

Although the Brazilian botanic gardens have a strategic commitment to environmental education, conservation and research, this study indicates that significant improvements are needed to improve practice. One case study that points the way forward for multidisciplinary recovery teams is for *Dimorphandra wilsonii* (Fabaceae), coordinated by the FZBBH in partnership with other institutions. It includes analyses on cultivation, phenology, genetics, reproductive biology and reintroduction (Fernandes *et al.*, 2007; Fonseca *et al.*, 2010; Fonseca *et al.*, 2012; Fernandes & Rego, 2014). This project supported the development of an Action Plan for the species and has the potential to become a model for other multidisciplinary studies in Brazil (Martins *et al.*, 2014).

The few reintroduction initiatives undertaken so far suggest that botanic gardens are not delivering an integrated approach to conservation. Additional investments into applied research involving cultivation and propagation of plants are of great relevance for reintroduction and restoration projects. An additional area of potential application is linking the development of cultivation techniques to counter the damaging trade in wild specimens. The Jardín Botánico de la UNAM in Mexico has developed cultivation protocols for 31 per cent of the threatened species from the national Red List with the objective of discouraging their illegal trade and overexploitation (Caballero, 2013).

Environmental education is a common activity among the Brazilian botanic gardens but only 13 (50 per cent) use threatened species as the focus of their education activities. Despite the limited conservation value of some collections, they are of great value for education and display and can be integrated in programmes to fund and promote plant conservation (Maunder *et al.*, 2001a).

Recommendations

Botanic gardens should use the most effective tools available to directly support species survival in the wild, through species recovery work that can include on site population management, ecosystem restoration and, when appropriate, reintroduction (Maunder *et al.*, 2004). We also consider that, to be effective, botanic gardens should have the highest quality of standards for documentation and verification as possible (Rae, 2011).

We suggest that Brazilian botanic gardens study the widely adopted approach of national collections as practised in the USA, Australia and the Netherlands. The traditional model has a focus on taxonomic representation for a particular plant group, but we suggest that the Brazilian model focuses on being a centre of excellence for the

conservation of that group, ideally at a regional or state level. This approach would focus on building the scientific and horticultural resources to support the conservation of particular plant groups.

We present these proposed actions to improve the conservation capacity of the Brazilian botanic gardens:

1. The effective use of botanic garden facilities is dependent upon a national and regional strategic framework that allows the targeted use of botanic garden expertise to avoid species extinctions. Each botanic garden should design and implement institutional conservation and collection plans that are developed with regional plant conservation task forces. Investments should be driven by the imperative of avoiding extinction rather than increasing the collections of threatened species as influenced by Target 8 of the GSPC. This emphasis on avoiding species extinction would necessitate *in situ* work as well as the traditional focus on *ex situ* activities. Ideally, new botanic gardens should be located where there is the greatest need for integrated plant conservation.
2. Botanic gardens are encouraged to develop national centres of excellence for priority threatened plant groups; the scientific and horticultural expertise, for example in species recovery and habitat restoration, can then be used to stop extinctions. This would entail developing expertise in the conservation biology and conservation management of groups poorly represented in botanic gardens, such as Asteraceae or Fabaceae.
3. National standards and performance indicators for collection documentation and management should be utilised to improve the effectiveness of conservation and the viability of cultivated populations.
4. Regional task forces and botanic garden centres of excellence should build effective collaborations with universities, plant genetic resource agencies and *in situ* conservation agencies to ensure the effective use of existing resources.
5. A significant investment must be made in training conservation-focused horticulturists and curators who can manage conservation collections.
6. Botanic garden education programmes should be focused on the value of plant diversity for Brazil, the uniqueness of Brazil's botanical diversity, the conservation issues of the region and showcasing the conservation work of the regional plant conservation teams.

CONCLUSIONS

While Brazilian botanic gardens have improved their contribution to conservation in the last few decades, the use of botanic garden plant collections for research, recovery, reintroduction and restoration is still limited to a few examples. However, with the production of the List of Brazilian Flora and the national Red List, botanic gardens have an opportunity to align their programmes with conservation priorities.

In order for botanic gardens to play a more effective role in conservation we argue that they no longer brand themselves as *ex situ* facilities, but as conservation institutions focused on halting plant extinctions.

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