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ORIGINAL PAPER

Gaps in seed banking are compromising the GSPC's Target 8 in a megadiverse country

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Abstract Ex situ seed conservation is an effective strategy to help safeguarding plants from extinction. The updated Global Strategy for Plant Conservation's (GSPC) Target 8 aims to include 75% of threatened plant species in ex situ collections by 2020, preferably in the country of origin. Halfway through the updated GSPC program, we evaluate the current state of knowledge and practice of ex situ seed conservation of threatened species from megadiverse Brazilian flora, contributing to this Target. We identify knowledge gaps and costs to achieve Target 8 through seed banking in Brazil within the time constraints of the GSPC and in a scenario of recent science budget funding cuts. Knowledge on seed storage behavior is available only for 24 Brazilian species (1.3%). Seed desiccation tolerance was concluded for 175 of 228 species, feasibly allowing safe storage of most Brazilian species at sub-zero temperatures. However, only 26 species (1.3%) are effectively banked in research institutions. Surprisingly, the percentage of banked threatened species hardly increased in the first 5 years since the update of the Target (0.55%, 2011–2015), and Brazil now faces the challenge of banking almost 1500 species during

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2016–2020. Despite a major lack of commitment of Brazilian institutions and of knowledge to achieve the Target, the costs for banking the remaining species were estimated to be only US$3.9 million. We call for a nationwide coordinated effort of government agencies, policy makers and research institutions to include ex situ seed conservation in the environmental agenda to pursue achievement of the Target by 2020.

Keywords Brazil · Conservation policy · Economic costs · Seed storage · Threatened species

Introduction

Ex situ conservation is an effective strategy to preserve plant species diversity (Maunder et al. 2004; Li and Pritchard 2009), which ultimately helps to safeguard them from extinction and provides material for habitat restoration and reintroduction of threatened taxa (Havens et al. 2006). In 2010, the Convention on Biological Diversity (CBD) updated the Global Strategy for Plant Conservation (GSPC) created in 2002 with a second phase, which aims to slow down the ongoing global plant extinction through 16 outcome-oriented global targets for the period 2011–2020 (CBD 2010). Specifically, GSPC Target 8 seeks the inclusion of at least 75% of threatened plant species in ex situ collections, preferably in the country of origin, and at least 20% available for recovery and restoration programs. Concerns about this critical ex situ plant conservation strategy, mandatory for GSPC signatories including Brazil, have led to initiatives aimed to engaging seed banks in native species conservation worldwide (Maunder et al. 2004; Li and Pritchard 2009; Hay and Probert 2013).

Combined actions of scientific effort from research institutions and resource investment from government agencies are key procedures to achieving seed conservation and banking of threatened species central to GSPC Target 8. In this regard, two major issues should be broadly considered, beyond merely collecting samples and increasing the accessions of seeds from wild species (Walters et al. 2005; Hay and Probert 2013). Firstly, high quality seed collections are required to maintain their viability over time for long-term conservation (Godefroid et al. 2010) and for seed-based restoration programs (Kildisheva et al. 2016 and references therein). Considering the current knowledge gaps in seed germination and storage behavior of many threatened species, scientists should focus research on these traits with an eye to the current ex situ conservation policy (Hay and Probert 2013; Fu et al. 2015; Ribeiro et al. 2016). Secondly, it is crucial to align the sources of science funding and government commitments with the international conservation agenda as required to meet the GSPC's Target 8 by 2020. Although it has been estimated that costs of ex situ seed banking is only 1% of that of in situ conservation (Li and Pritchard 2009), development and upkeep of genebanking may still be jeopardized under the current scenario of a global financial crisis and subsequent research budget cuts. Therefore, a few caveats in both science and policy need attention if the promises of long-term conservation of threatened plants in seed banks are to be attained.

Here, we evaluate the current situation of ex situ seed conservation of threatened species in Brazil and envision a conservation policy under the perspective of the GSPC's Targets 2011–2020 and the recent federal science budget funding cuts (Gibney 2015). Brazil harbors the world's most diversified seed-bearing flora, with 32,796 species and 56% of the vascular flora endemic to its territory (Forzza et al. 2012). The country also includes two biodiversity hotspots, the Atlantic Forest and the Cerrado (Myers et al. 2000) as well as the Amazon forest, the world's largest rainforest. Brazil has demonstrated an environmental leadership over the last two decades after holding the United Nations Conferences on Sustainable Development (i.e., Rio Declaration 1992), playing a vital role in international conservation. The country has created the largest protected area network on the planet and has developed deforestation reduction programs, which have substantially attenuated Amazonian habitat loss (Nepstad et al. 2009; Scarano et al. 2012). However, these achievements are progressively being compromised by increases in downgrading and downsizing of protected areas resulting from mining and building dams in response to rising demands of electricity, and subsequent shifts in federal legislation and governmental policy (Bernard et al. 2014; Ferreira et al. 2014; Soares-Filho et al. 2014).

To achieve a detailed and comprehensive knowledge of such a diversity and its conservation status, Brazil has successfully developed a complete, but periodically updated, online flora and a red list within a tight schedule (2008–2015) at a relatively low economic cost (US$3.2 million, R. Forzza and G. Martinelli, personal communication), meeting Targets 1 and 2 of the GSPC (CBD 2010). This nationwide initiative has uncovered a high number of threatened seed plant species, which currently includes 2018 national (MMA 2014) and 409 global records indexed in the IUCN's Red List (IUCN 2015). This allows us to evaluate the current status of ex situ seed conservation of threatened species and to compare the investment of monetary resources with GSPC's Targets 1 and 2. A germplasm-seed bank was created in 1976 to safeguard economically relevant seeds, protecting the genetic resources of ca. 6000 species that support nutrition and agriculture (MMA 2015). However, data about seed banking of threatened species has been largely overlooked and remain unrevealed, therefore casting doubts on whether achievement of Target 8 of the GSPC is feasible by 2020.

Halfway through the second phase of the GSPC program 2011–2020, we analyze what progress has been made from an ex situ seed conservation perspective since the targets updated in 2010 and assess the actions that need to be taken for the remaining 5-year period. Our specific goals were (1) to quantify the number of Brazil's threatened species conserved in ex situ seed banks and the subsequent gaps contributing towards achieving the GSPC's Target 8; (2) to calculate the economic costs for banking uncollected threatened species and its percentage of the annual budget of Brazil's Ministry of the Environment; (3) to assess the current state of knowledge on seed storage of threatened native species; (4) to estimate the likelihood of desiccation tolerance, allowing safe storage at sub-zero temperatures; and (5) to steer decision-making relevant to science and conservation policies aimed at resolving the main problems to ensure the achievement of the GSPC's Target 8 in Brazil.

Materials and methods

Ex situ seed conservation

We quantified the total number of Brazil's native species collected and conserved in ex situ seed bank collections. We surveyed only species collected in Brazil and included in the Brazilian Flora 2020 project, the official database constantly updated by almost 600 plant taxonomists (http://floradobrasil.jbrj.gov.br/). We investigated banked species for ex situ conservation purposes through nine Brazilian research institutions (Table 1) and the UK's Millennium Seed Bank (MSB). Although living collections count towards GSPC's Target 8, we excluded ex situ collections from botanic gardens or other scientific research organizations dedicated to plant cultivation and display. We exclusively considered seed banks due to two main reasons. Firstly, they provide an effective emergency measure in case of habitat destruction, diseases or predators, complements in situ conservation by means of genetic improvement when introduced in fragmented populations, favors long-term storage, and may assist large-scale restoration (Schoen and Brown 2001; Hay and Probert 2013). Secondly, information about ex situ collections of threatened species in botanic gardens in Brazil has already been reported (Weigand Jr et al. 2011), but knowledge surrounding the status of ex situ conservation from seed banks in this megadiverse country remains limited. Thus, cultivated, ornamental, naturalized, exotic, invasive species and species banked for the purposes of crop genetic improvement, integrating agro-biodiverse systems, and crop-related species were not included in our database. In this regard, no crop wild relative is indexed in the Brazilian Red List (MMA 2014) or the Brazilian species listed under the IUCN Red List (IUCN 2015). Under these criteria, we quantified the number of species collected regardless of the number of accessions per species. For every species, we also recorded the collection year and used the first year of collection when there was more than one accession banked.

We assessed the percentage of threatened species banked against both the Brazilian Red List (MMA 2014) and the IUCN Red List (IUCN 2015). We only recorded vulnerable, endangered and critically endangered species. The three lower risk categories (conservation dependent, nearly threatened and least concern species) and species that have not been evaluated or do not have sufficient data (i.e., not evaluated and data deficient, respectively)

Table 1 Brazilian institutions surveyed for ex situ seed conservation purposes, including number of banked native species collected in the country, and number of banked threatened species included in the Brazilian Red List (MMA 2014) and the IUCN Red List (IUCN 2015)

Research institution	Abbreviation	Native species banked	Species in the Brazilian Red List	Species in the IUCN
Amazon Native Seed Center	CSNAM	–	–	–
Belo Horizonte Zoo-Botanic Foundation	FZB-BH[a]	–	–	–
Brazilian Institute of Environment and Renewable Natural Resources	IBAMA	–	–	–
Campinas Agronomic Institute	IAC[a]	–	–	–
São Paulo Forest Institute	IF	–	–	–
Genetic Resources and Biotechnology Center of the Brazilian Agricultural Research Corporation	CENARGEN-Embrapa	185 (32.4)	5 (20.0)	5 (16.7)
National Institute of Amazonian Research	INPA	–	–	–
Porto Alegre Zoo-Botanic Foundation	FZB-RS	43 (7.5)	3 (12.0)	1 (3.3)
Rio de Janeiro Botanical Garden	JBRJ[a]	344 (60.1)	17 (68.0)	24 (80.0)

Numbers in brackets indicate the percentage of species banked in each institution

[a] Botanic Gardens Conservation International (BCGI) members contributing towards the GSPC (BCGI 2016)

were not considered as they are not categorized as threatened by the IUCN (2015). Likewise, species that are extinct or extinct in the wild were not considered either. Subsequently, we determined the number of: (1) threatened species banked from the first collection year until 2002; (2) threatened species banked during the first phase of the GSPC, before updating (2003–2010); (3) threatened species stored in the first half of the elapsed time (2011–2015) towards the updated GSPC's deadline; and (4) threatened species that should be banked during the remaining 5-year period (2016–2020) to achieve the GSPC's Target 8.

Economic costs

To assess the feasibility of achieving the GSPC Target 8, we investigated the likely economic costs to bank seeds in Brazil. We assumed a cost of US$2600 per species (£2100, including transport, fieldwork, seed processing, banking, viability assessment and all running and staff costs for that; Li and Pritchard 2009). This estimate is based on a global average accurately estimated from collections made from a wide range of countries and is consequently well-funded for any particular region or country (Dickie, personal communication). Brazil is a huge country where research institutions are unevenly distributed geographically (Ribeiro et al. 2016) and biodiversity assessment is strongly biased spatially, decreasing with the distance from access routes (Oliveira et al. 2016). Therefore, long-distance transport between seed collection sites and the storage facility is a cost that is extremely difficult to assess and may also increase the global estimate. In contrast, the Brazilian conditions (lower staff costs and seed storage costs; J.G. Padúa, personal communication) and the current local currency exchange rate against US$ has significantly devalued from 2009 (about a two-fold decrease), may disproportionately reduce cost estimates. In order not to underestimate the current economic costs to achieve the Target 8 in Brazil, we consider US$2600 an appropriate estimate to attain this purpose by 2020.

Seed storage research

To evaluate the current state and available knowledge on seed storage behavior, a mandatory condition for ex situ conservation, we quantified the number of wild and threatened native species studied for this purpose. To do this, we updated the literature surveyed in Ribeiro et al. (2016), which reviewed the published literature on seed ecology research retrieved on six seed topics (seed germination, seed dormancy, seed banks, seed dispersal, seed predation and seed removal) for Brazilian species by including records obtained in the Scielo (www.scielo.br) and the Web of Science databases between 1976 and 2013 using the search terms "seed" or "seeds" and "Brazil". Then, we exclusively selected the papers for the topic "seed banks" (which included seed longevity, seed storage and seed viability for ex situ conservation as well as seed storage, seed rain and seed loss dynamics within the soil) and subsequently updated the databases using the same search terms, by surveying articles published in 2014 and 2015 for this topic. Among the 150 studies and 494 wild native species reported for seed banks between 1976 and 2015, we selected those papers analyzing longevity, persistence and viability of seeds for ex situ conservation in seed banks. Therefore, we excluded studies related to the natural storage of seeds within the soil, seed rain or seed loss dynamics. The definitions for the three classes of seed storage behavior orthodox, intermediate and recalcitrant were followed according to Roberts (1973) and Ellis et al. (1990). Orthodox seeds are tolerant to desiccation and can be stored at conventional −20 °C, whereas recalcitrant seeds cannot be dried without damage (Roberts 1973) and require cryo-storage (Li and Pritchard 2009; Walters et al. 2013). Intermediate seed storage behavior occurs when dry seeds are injured by sub-zero temperatures (Ellis et al. 1990). Over the full database, we quantified the papers published into three temporal categories: (1) from the first publication year recorded until 2002; (2) for 2003–2010 to evaluate for expected research improvements since GSPC's targets came into force; and (3) for 2011–2015, to check for expected improvements after the update of the targets.

Seed desiccation tolerance

To estimate seed desiccation tolerance in threatened species, another requirement for ex situ conservation at either conventional −20 °C or in cryo-storage, we used the information from the literature (see above) to identify the species that produced recalcitrant seeds. In addition, we extracted information on Brazilian species from the Royal Botanic Gardens Kew's Seed Information Database (SID; Royal Botanic Gardens Kew 2016), and from routine germination tests performed at RBG Kew's MSB. After eliminating the overlap, information for 228 species was obtained. The assumption was made that seeds can be safely stored at sub-zero temperatures if seeds are not recalcitrant, effectively allowing ex situ conservation. Absent desiccation tolerance would not restrict safe cryo-storage but information is scarce and was not considered for inclusion here (Li and Pritchard 2009).

Results

Ex situ seed conservation

We found seeds of Brazilian species banked to international conservation standard in only four institutions, Brazil's Genetic Resource and Biotechnology Center (CENARGEN-Embrapa), Porto Alegre Zoo-Botanic Foundation (FZB-RS) and Rio de Janeiro Botanical Garden (JBRJ) (Table 1), and the UK's Millenium Seed Bank. Overall, 790 native species are ex situ conserved and 72% of these are stored in Brazil (Table 2). Of these, 29 are IUCN Red Listed species and only 26 are from Brazilian Red Listed species. Most of these threatened species are banked in one institution, the JBRJ (Table 1; Appendix 1 in Supplementary material). Almost 1500 species listed in the Brazilian Red List would need to be banked during 2016–2020 to attain the GSPC Target of a minimum of 75% of threatened species stored in seed banks. This number is reduced to 278 species when considering the IUCN Red List. Thus, we detected a major gap in the percentage of threatened species collected and conserved ex situ in seed banks to achieve the GSPC's Target 8. Although the adoption of GSPC 2020 has doubled the number of banked threatened species, this gap has hardly decreased from 2011 to 2015 (Table 2).

The costs for banking 1500 Brazilian species were estimated to be nearly US$3.9 million, ca. 0.4% of the annual budget of Brazil's Ministry of the Environment (Fig. 1). The cost is similar to the funds allocated to accomplish the GSPC's Targets 1 and 2 (i.e., Brazilian Flora and Brazilian Red List projects), and represents only a quarter of the investment in banking crops (Fig. 1).

Table 2 Number of species of the Brazilian flora, including number of threatened species both at national (Brazilian Red List) and global level (IUCN Red List), which have been stored in ex situ national seed banks and MSB

Species	Brazilian Seed Banks				Millenium Seed Bank				Total			
	1976–2002	2003–2010	2011–2015	Total	1971–2002	2003–2010	2011–2015	Total	1971–2010	2003–2010	2011–2015	Total
Banked	136 (0.41)	189 (0.59)	247 (0.75)	572 (1.75)	218 (0.66)	0 (0.00)	0 (0.00)	218 (0.66)	354 (1.07)	189 (0.59)	247 (0.75)	790 (2.41)[a]
Threatened												
Brazilian Red List	2 (0.10)	11 (0.55)	12 (0.59)	25 (1.24)	1 (0.05)	0 (0.00)	0 (0.00)	1 (0.05)	3 (0.15)	11 (0.55)	12 (0.59)	26 (1.29)[b]
IUCN	1 (0.25)	18 (4.40)	10 (2.44)	29 (7.09)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.25)	18 (4.40)	10 (2.44)	29 (7.09)[c]

Numbers in brackets show the percentage of species total representativeness

[a] 32,796 species of angiosperms have been reported for Brazil (Brazilian Flora 2020 project; www.floradobrasil.jbrj.gov.br, Accessed on 31st December 2015)

[b] 2018 species are listed in the Brazilian Red List (MMA 2014)

[c] 409 species of the Brazilian Flora are listed in the IUCN Red List (IUCN 2015)

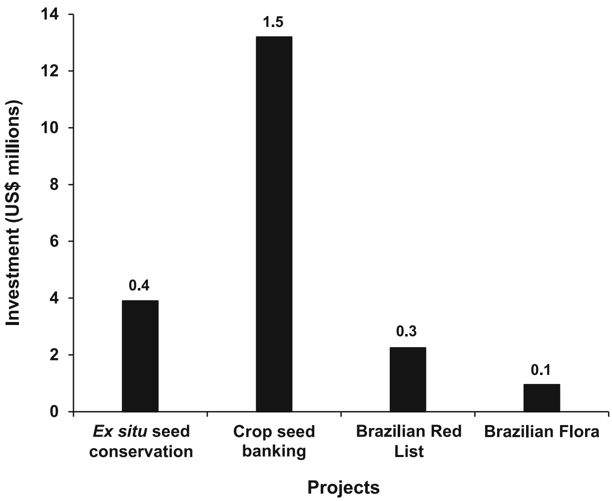

Fig. 1 Budgetary estimate (US$ million) to achieve the GSPC's Target 8 in Brazil in relation to the economic costs invested to achieve GSPC's Target 1 (Brazilian Flora), Target 2 (Brazilian Red List) and investment in banking crops. Percentage over the Ministry of the Environment's budget 2014 shown above *each bar*

Seed storage research

We found 125 studies published between 1986 and 2015 covering 200 species that met our search criteria. This number represents <1% of Brazilian native seed species described until 31st December 2015 (Table 3). Out of the 125 papers, ca. 30% were published during the first 5 years elapsed since the update of the GSPC targets. However, the number of species surveyed during this period decreased proportionately compared with the 25 years before (0.07 vs. 0.54%, respectively; Table 3). The implementation of the GSPC targets resulted in a three-fold increase in number of studied species (Table 3). Nearly twice as many IUCN-listed threatened species were studied compared to those on the Brazilian Red List, although values were still very low (<3% for both lists; Table 3). A list of all threatened species studied in terms of seed storage behavior per year is provided (Appendix 2 in Supplementary material). Specifically, the first phase of the GSPC's targets

Table 3 Number of species of the Brazilian flora, including number of identified threatened species both at national (Brazilian Red List) and global level (IUCN Red List), which have been recorded in studies based on ex situ conservation (i.e., viability for seed bank storage)

Species	1986–2002	2003–2010	2011–2015	Total
Studied	44 (0.14)	132 (0.40)	24 (0.07)	200 (0.61)[a]
Threatened				
Brazilian Red List	7 (0.35)	15 (0.73)	2 (0.01)	24 (1.19)[b]
IUCN	3 (0.73)	7 (1.71)	2 (0.49)	12 (2.93)[c]

Numbers in brackets show the percentage of species total representativeness

[a,b,c] See Table 2

(2003–2010) involved about a two-fold increase in number of studies of threatened species. Overall, more than 10% (24 species) and 5% (12 species) out of the 237 studied species are included in the Brazilian Red List and in the IUCN Red List, respectively.

Seed desiccation tolerance in Brazilian angiosperm species was considered safe for 175 out of 228 species or 77%, but unsafe for 53 species (Appendix 3 in Supplementary material). Assuming a similar proportion of desiccation tolerance among threatened species, this makes it feasible to reach GSPC's Target 8 and safely store at least 75% of threatened plant species in ex situ collections by 2020.

Discussion

We demonstrated that a major gap in seed banking of threatened species compromises the Brazilian implementation of the GSPC's Target 8 on ex situ conservation. We also detected noticeable knowledge gaps in seed storage research that assesses quality and conditions of long-term storage, suggesting that there is a gap in both knowledge and practice. Moreover, we show that the implementation of the updated GSPC's Target 8 in 2010 has not reversed this tendency, despite progressing beyond the halfway point to the 2020 deadline. Altogether, our results show a lack of commitment from Brazilian government and the scientific community to the purposes specifically expressed in the revised GSPC's Target 8, at least in terms of seed banking. Our estimates suggest that it is economically feasible to pursue achievement of the GSPC Target 8 by 2020. We provide some recommendations for both scientific institutions and governmental agencies in driving future research efforts for an effective ex situ seed conservation policy despite a scenario of reduced science funding.

Although Brazil is internationally recognized as a leader in environmental protection, and conservation policies have improved and research investment in biodiversity and on-ground initiatives (e.g., inventory of Brazilian megadiverse flora; Forzza et al. 2012) have intensively increased during the last decade (Scarano et al. 2012), ex situ seed conservation is still neglected and the country is clearly steering towards missing Target 8. This gap is possibly due to prioritization of conservation initiatives other than ex situ strategies and associated allocation of funds for the competent institutions responsible for overseeing their attainment. Brazil has successfully implemented a strategy to achieve the GSPC's Targets 1 and 2, and has traditionally contributed to ex situ conservation of economically relevant species (CBD 2010; León-Lobos et al. 2012; MMA 2015), as stated by GSPC's Target 9 (see below for details). However, no national strategy has so far been adopted to cope with the limited progress towards Target 8 and Brazil still faces a great effort to efficiently conserve its megadiverse flora (Dias and Hoft 2013); despite the National Center for Flora Conservation (CNCFlora) created by the Rio de Janeiro Botanical Garden (JBRJ) in 2008 to document and conserve plant diversity in Brazil in collaboration with research institutions and environmental agencies worldwide, focusing human and financial efforts on achieving GSPC Targets 1, 2, 3, 7, 15 and 16 (Sharrock et al. 2014). Although the Brazilian budget for science and environment has fallen since the economic decline in 2014 (Gibney 2015), our budgetary estimates to achieve the GSPC's Target 8 show a similar funding to that invested to attain Targets 1 and 2 and likewise require a low monetary resource (Fig. 1). Therefore, re-allocating resources towards an infrastructure with a geographical central location (for logistic reasons) as well as proper botanical support to increase the seed banking effort renders a feasible option to achieve the Target in Brazil. In terms of time, 31.5 man-years (m/f) of staff time were spent collecting 733 species as part of an effort to bank the UK flora (Alton and Linington 2001). Based on this information and after acknowledging the diversity and conservation status of Brazilian seed plants it would take at least 64.5 man-years, a conservative estimate given the size of Brazil and the limited accessibility of threatened plant populations compared with the UK, to store 1500 threatened species in seed banks. Although this is feasible, achieving this depends strongly on available funds. Alternatively, Brazil could reduce seed banking of threatened species to 60% to achieve the GSPC's Target 8 in a megadiverse flora context, as implemented in South Africa (Sharrock et al. 2014), which still requires major re-allocation of funding and an effective national strategy on achieving Target 8.

The GSPC's Target 8 does not exclusively refer to ex situ conservation in seed banks, as it could also include living or tissue collections. In this regard, botanic gardens have come to play an essential role in conserving threatened plants against extinction in the wild over the last two decades (Havens et al. 2006; Hardwick et al. 2011). To date, ex situ living collections in Brazil are estimated to comprise around 400–450 native threatened species across 26 national botanic gardens, which amounts to ca. 20% of the national threatened list (M.L. Costa, personal communication). This percentage hardly involves any improvement in ex situ conservation of threatened species in botanic gardens from 2010 (18%; Weigand Jr et al. 2011) and is still far from reaching the records at the global level (29%; Sharrock et al. 2014; see also Godefroid et al. 2011 for European plant species). Large efforts need to be made to improve the rate of safely banked threatened species. Brazil only contains five botanic gardens associated to the GSPC 2020 (BGCI 2016), but only one (JBRJ) performs seed conservation. However, other non-member botanic gardens should also contribute towards the GSPC's Target 8, following the FZB-RS. As pointed out above, the conservation of threatened plant species in seed banks provides an effective and cost-effective conservation measure which complements in situ conservation and provides supplies for plant community restoration. Therefore, we strongly urge botanic gardens to play a more active role in conservation and restoration science and practice through prioritizing seed banking of threatened species.

Brazil has extensively demonstrated its commitment and traditional contribution to ex situ conservation of economically relevant species (León-Lobos et al. 2012; MMA 2015). These activities contributed to increased knowledge on agrobiodiversity and crop wild relatives, including the banking of 790 native species and the conservation of a national collection of genetic samples, as stated by GSPC's Target 9 (CBD 2010). Although Brazil harbors the world's highest plant diversity, the socio-economic conditions of the country have historically directed efforts to preserve plant genetic resources for food and agriculture rather than assisting biodiversity conservation actions as proposed by Target 8. This decision has made the country one of the most active international providers of genetic heritage for use in agricultural resource and development (Galluzzi et al. 2016). The Genetic Resources and Biotechnology Center of the Brazilian Agricultural Research Corporation (CENARGEN-Embrapa) enhanced its genetic resources conservation capacity in 2014 through the establishing the third largest gene bank of the world, at a cost of US$13.2 million and with capacity to store over 1000,000 seed samples under different preservation methods (MMA 2015). Therefore, the country has well-developed and high-quality logistics infrastructures, a broad professional experience, and qualified human resources to achieve the GSPC's Target 8.

However, some scientific, political and economic aspects should be taken into consideration. Scientifically, major knowledge gaps in seed desiccation tolerance of threatened species hamper our capacity to conserve seeds efficiently (Hay and Probert 2013). This scenario could become even worse if some endangered species become extinct in the near future or if the number of threatened species increases (Feeley and Silman 2009; ter Steege et al. 2015). New endangered species are being described at a regular frequency and we still lack sufficient knowledge on the conservation status of many of them (Forzza et al. 2012; Sousa-Baena et al. 2014). More research based on seed desiccation tolerance is imperative to maximize the efficiency of seed-based restoration practises (Kildisheva et al. 2016; Ribeiro et al. 2016). Numerous plant species occurring in tropical rainforests produce recalcitrant, desiccation-intolerant seeds, requiring costly and specialized infrastructure and staff for ultra-cold storage (i.e., cryopreservation: Li and Pritchard 2009; Walters et al. 2013; Pritchard et al. 2014). In this regard, we assume that the expected higher frequency of recalcitrant seeded-species in the Amazon and the Atlantic Forest (Pritchard et al. 2014) requires a greater investment in research and long-term seed storage. Otherwise, seed conservation for most species, especially from the Brazilian seasonally dry biomes (Caatinga, Cerrado and Pantanal), will likely be highly effective at conventional seed bank conditions (León-Lobos et al. 2012). This was supported by our estimates that 76% of threatened species are likely to have seed desiccation tolerance (Appendix 3 in Supplementary material). Thus, a large portion of the threatened flora can be easily stored under conventional methods (−20 °C) and is thus capable of contributing to the achievement of the GSPC's Target 8.

Following the specific responses from other megadiverse countries, Brazil should adopt a nationwide strategy for ex situ seed conservation to pursue the achievement of the GSPC's Target 8 by 2020. For example, the Chinese Germplasm Bank of Wild Species was established in 2008 to achieve the seed conservation Target before 2020, developing a nationwide seed-collecting network that includes 71 organizations, research institutes, universities and nature reserves that are actively training staff and collecting seeds from their local flora for long-term conservation (Cai 2015). The Australian Seed Bank Partnership is a national alliance of 12 institutions (botanic gardens, state environment agencies and NGOs) which aims to bank seeds of 80% of Australia's threatened flora by 2020, developing several initiatives as "The 1000 species project" based on seeds collected from 1000 threatened and endemic species (CHABG 2011). A total of 22 groups of action make up the Mexican National Strategy for Plant Conservation, which has established the Seed Bank of Iztacala to assume long-term seed conservation from threatened species from the arid and semiarid areas of Mexico and promote ongoing development and training programmes in field and laboratory work for students and technicians (León-Lobos et al. 2012). Therefore, the Brazilian conservation institutions and decision-makers should consider a similar broad approach to maximize the effort of banking threatened species. The Genetic Heritage Act (Act 13.123/2015) now allows ex situ conservation of genetic resources outside national territory. This recent change in legislation now provides unique opportunities for cross-country partnerships that could play a major role in reversing the ill-fated scenario of not achieving Target 8. In addition, we suggest the hosting of annual evaluation meetings carried out by expert review teams to measure progress towards implementation of the national Target.

Environmental licensing is a mandatory procedure for any company whose economic activities cause environmental damages. In this process, governmental institutions establish the policies needed to mitigate or compensate environmental damages caused by such activities. Today, Brazil is in the process of providing a large number of licenses for mining and hydroelectric dams across virtually all of the nation's regions (Ferreira et al. 2014). We suggest that environmental programs involving seed banking of threatened species found in the area under the influence of the enterprises should be prioritized before conceding the operation license. Additionally, we recommend that environmental institutions allocate part of their compensation resources directly to programs related to seed banking of threatened species. For instance, after the largest environmental disaster in Brazil involving a rupture of a mining dam in Mariana, the penalties for mining companies can be in the order of billions of dollars (Garcia et al. 2016). Part of this budget must be employed for ecological restoration, but part of it could also be directed towards improving seed banks of threatened species from the Atlantic Forest, a biome directly affected by the calamity. Unless decision makers entice both governmental institutions and private initiative into tangible actions toward seed banking, the GSPC's Target 8 looks unlikely to be achieved in Brazil. With the imminent threat of extinction to this megadiverse flora, such actions are urgently required and ought to mend the gaps in ex situ seed conservation, turning the tide for the threatened species. Undeterred action would have paramount importance for the country to ratify global policies and secure its internationally recognized environmental leadership.

Conclusions

This study reports a noticeable gap of knowledge and practice of ex situ seed conservation of threatened species in Brazil, which we fear will persist, given the worrying lack of nationwide strategies and conservation policies aimed at achieving GSPC's Target 8 by 2020. However, the relatively low economic costs estimated to attain the Target, despite the national financial crisis and subsequent research budget cuts, suggest achieving Target 8 is economically feasible in a short-term. Moreover, the effective commitment in reaching the required and relevant Targets 1 and 2 to subsequently address Target 8, including recent high-quality infrastructures and the traditional national background for ex situ conservation of genetic resources for food and agriculture, provide an ideal setting to successfully contribute to achieving the mandatory global goals. We call for the coordinated and structured action of governmental and research institutions, together with the international exchange of experiences of other megadiverse countries, to increase our knowledge and practice of urgent ex situ seed conservation of threatened species of the Brazilian megadiverse flora.

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