



Ex situ conservation of threatened plants in Brazil: a strategic plan to achieve Target 8 of the Global Strategy for Plant Conservation

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Abstract

With increasing rates of habitat destruction and species loss, *ex situ* conservation is gaining global momentum and reluctance in relying on *ex situ* conservation is rapidly giving way to a more optimistic, strategic view. Target 8 of the Global Strategy of Plant Conservation calls for at least 75 percent of threatened plant species in accessible *ex situ* collections, preferably in the country of origin, and 20 percent of them included in recovery and restoration programs. Here, we provide updated information on Brazil's progress towards Target 8 through a nationwide examination of how many threatened species were conserved in *ex situ* collections in Brazil. Our data comprised whole plants (living collections), seed (seed banks) and tissue cultures (*in vitro*). Of the 2,113 threatened species, at least 452 (21.4%) species were conserved in *ex situ* collections, an increase in 4% of living organisms and 96% of seeds when compared to a previous assessment. Since it is unlikely Brazil will achieve Target 8 by 2020, we also discuss public policies and strategies to help overcome key bottlenecks preventing its achievement and propose revised goals for the GSPC 2020–2030.

Key words: botanic gardens, conservation policy, GSPC, living collection, seed conservation, seed bank.

Resumo

Com as crescentes taxas de destruição de habitats e perda de espécies, a conservação *ex situ* vem ganhando ímpeto global e a relutância de se depender da conservação *ex situ* vem rapidamente dando lugar a uma visão mais otimista e estratégica. A Meta 8 da Estratégia Global de Conservação de Plantas prevê a incorporação de pelo menos 75% de espécies ameaçadas em coleções *ex situ*, preferencialmente no país de origem e 20% delas disponíveis para programas de restauração ecológica. Nós fornecemos informações atualizadas sobre o progresso brasileiro sobre a Meta 8 através de uma investigação sobre quantas espécies ameaçadas estão conservadas em coleções *ex situ* no Brasil. Nossa base de dados compreende plantas inteiras (coleções vivas), sementes (banco de sementes) e cultura de tecidos (*in vitro*). Das 2,113 espécies ameaçadas, pelo menos 452 (21.4%) espécies estão conservadas em coleções *ex situ*, um aumento de 4% para coleções vivas e 96% para sementes comparado com avaliações anteriores. Como é improvável que o Brasil vá atingir a Meta 8 até 2020, nós discutimos políticas públicas e estratégias para ajudar a superar os obstáculos que impedem a sua realização e propomos metas revisadas para a GSPC 2020–2030.

Palavras-chave: jardins botânicos, política de conservação, EGCP, coleções vivas, conservação de sementes, banco de sementes

Introduction

Plants are widely recognized as a pivotal component of the world's biodiversity and an essential resource for mankind. In addition to the plant species used for food, timber, medicines and fibers, many wild species have great economic,

cultural and religious importance as future crops and commodities. Plants play a key role in maintaining the planet's environmental balance and ecosystem multifunctionality and provide an irreplaceable component of the habitats for the world's animal life (CBD 2010, decision X/17).

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Nevertheless, the survival of plant species and the ecosystem services they provide are both locally and globally threatened by anthropogenic activities (Heywood 2017; Pimm & Raven 2017), which resulted in the development of the Global Strategy for Plant Conservation (GSPC).

The GSPC is a global effort aiming to document, conserve and use sustainably plant diversity, as well as increasing awareness about plant diversity, capacitate and engage public to implement the 16 outcome-oriented targets by 2020 (CBD 2010, decision X/17). The rationale behind the 16 targets is that once the GSPC is put into practice, human societies will be able to secure essential ecosystem services (including food and energy security, use the potential of plants to mitigate and adapt to climate change, reduce the risk of plant extinction, explore the rich evolutionary legacy of plant diversity and increase awareness of the urgency of plant conservation (CBD 2010, decision X/17).

The original Target 8 of GSPC from 2002 called for 60 percent of threatened plant species in accessible *ex situ* collections, preferably in the country of origin, and 10 percent of them included in recovery and restoration programs. The revised Target in 2010 presently calls for at least 75 percent of threatened plant species to be included in *ex situ* collections, preferably in the country of origin, and at least 20 percent available for recovery and restoration programs.

The recent mid-term document reports good global progress made towards Target 8 (<<https://www.cbd.int/doc/meetings/sbi/sbi-01/information/sbi-01-inf-32-en.pdf>>). However, the mid-term report does not address the Brazilian progress towards Target 8. Two independent publications have recently assessed the Brazilian progress of the two major *ex situ* conservation strategies: living collections (Costa *et al.* 2017) and seed banking (Teixido *et al.* 2017). Unfortunately, information was not integrated between these studies, hence preventing any attempts of a nationwide Brazilian assessment of the progress towards Target 8. Here, we address the history, progress and future perspectives of Target 8 in Brazil by integrating data of threatened species in *ex situ* collections. Particularly, we 1) provide updated information on the progress of Target 8 through a nationwide consultation; 2) report the results of a web-based poll to estimate the conservation capacity in the country and to survey hurdles underlying the efforts for Target

8 implementation; 3) discuss public policies and strategies to overcome key bottlenecks preventing Target 8 achievement; and 4) propose revised goals for the GSPC 2020-2030.

Strategies for *in situ* conservation have long been the focus of biodiversity conservation worldwide. As a result of such historical developments, there is now international agreement that allocating particular parts of Earth to support biodiversity should be enough to achieve GSPC targets (Joppa *et al.* 2013; Watson & Venter 2017). However, owing to increasingly disappearing of natural habitats, and constantly growth in the number of imperiled plants, *ex situ* conservation has gained global momentum (Volis 2017; Liu *et al.* 2018). *Ex situ* conservation was defined in Article 2 of the Convention on Biological Diversity (CBD) (UNCED 1992) as “the conservation of components of biological diversity outside their natural habitats.” It involves the sampling, transference, and storage of target taxa from the collecting area and is generally used to safeguard species or populations that are at present or are potentially in danger of physical destruction, replacement, or genetic deterioration. The techniques for *ex situ* conservation currently used include seed (and spore) banks, field gene banks, *in vitro* storage, pollen banks, DNA storage, and living plants in botanic gardens (Hawkes *et al.* 2000; Pellegrini & Balatti 2016; O’Donnell & Sharrock 2017; Fig. 1). Botanic gardens and other *ex situ* facilities, and particularly seed banks are among the most extensive plant conservation resources in the world. *Ex situ* conservation is a safe, relevant, multipurpose and cost-effective way of preserving species and genetic diversity, and at the same time increase awareness of biodiversity. *Ex situ* collections can provide germplasm that can be reintroduced to

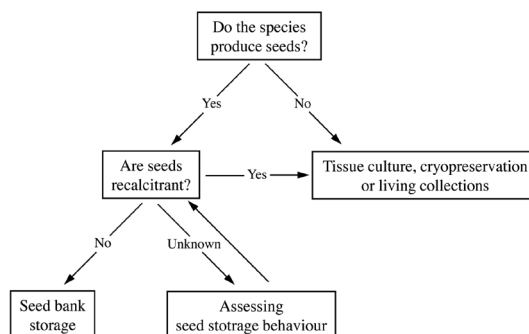


Figure 1 – Workflow of species traits needed to be addressed to orient the best *ex situ* conservation strategy.

their original or, where necessary, ecologically restored habitats (Cochrane *et al.* 2007). However, misconceptions and misperceptions of *ex situ* have prevented conservation biologists to recognize its potential and complementary roles in conservation (Guerrant *et al.* 2004).

Ex situ conservation also plays roles that are not fulfilled by *in situ* conservation. Such goals include conservation of species extinct in the wild (Oldfield 2009) and insurance against natural and anthropogenic threats to plants *in situ* (pollution, wars, political conflicts, dam bursts, etc; O'Donnell & Sharrock 2017). *Ex situ* conservation may be the only feasible strategy for species that will inevitably experience partial or full *in situ* loss of populations. Furthermore, costs of *ex situ* conservation are relatively low, and species can be conserved for hundreds of years in a relatively small place (Li & Pritchard 2009; O'Donnell & Sharrock 2017). To date, more than a third of plant taxa are represented in botanic garden collections (Mounce *et al.* 2017), showing the realized potential and relevance of *ex situ* collections.

Material and Methods

To monitor the Progress in implementation of GSPC's Target 8 in Brazil, we provide an updated list of threatened species in living collections (Costa *et al.* 2017, 2018) and seed banks (Teixido *et al.* 2017) based on a survey with 21 botanic gardens registered in the Brazilian Ministry of the Environment (MMA) and other Brazilian plant conservation institutions (Brazilian Agricultural Research Corporation and Instituto Florestal).

To estimate conservation capacity, we launched an online survey (<<https://goo.gl/forms/smjijRJ56rRgjn93>>) on August 6, 2017 that was advertised in social media, scientific societies, scientific meetings and the Brazilian Botanic Gardens Network. The survey was closed on December 18, 2017. The goal of the survey was to evaluate the conservation capacity of the country and the awareness of the conservation community towards the GSPC Target 8. Most (>78%) of the 75 respondents from 52 institutions were biologists and agronomists with skilled experience (68% hold a Ph.D title) in research and teaching. A high percentage (77%) of respondents work on seed ecophysiology focused on *ex situ* conservation and ecological restoration, but there was a strong bias towards species from the Atlantic Forest (53%) and the Cerrado (47%).

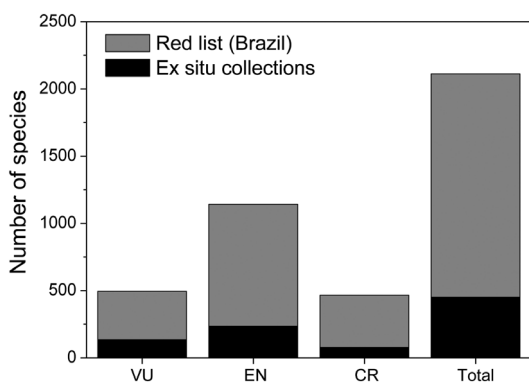


Figure 2 – Distribution of the 452 *ex situ* conserved (black columns) species and total number of the Brazilian Red List (grey columns) by threat category. (VU = vulnerable; EN = endangered; CR = critically endangered; NE = not evaluated).

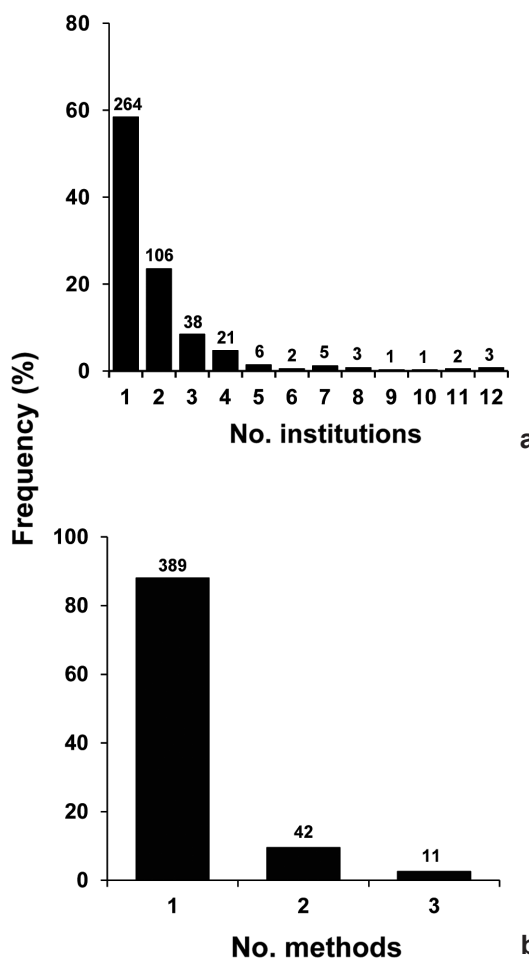


Figure 3 – a,b. Percentage of *ex situ* conserved threatened species – a. based on the number of accessions; b. based on the number of *ex situ* conservation methods. Absolute number of species are shown above each bar.

Results and Discussion

We found 452 species conserved *ex situ* or 21% of the Brazilian Red List (Brasil 2014), with 440 species conserved in arboreta or greenhouses, 52 species in seed banks, 18 species in field banks and eight species conserved *in vitro* [Table S1 (<<https://doi.org/10.6084/m9.figshare.7199750.v2>>)]. The distribution of these 452 species according threat category was as following: 53% Endangered, 30% Vulnerable and 17% Critically Endangered (Fig. 2). Nearly 60% of the *ex situ* conserved species had only one institution, and only six (1.3%) species had more than 10 institutions (Fig. 3a). Nearly 86% of the species were conserved through a single method, and only eleven species (2.4%) were conserved by three *ex situ* methods (Fig. 3b).

The great majority of plants were conserved in living collections of botanic gardens where the species in field banks were maintained by agricultural and forestry institutions. The number of Brazilian threatened species conserved *ex situ* in living collections and in seed banks has increased four percent and 96 percent, respectively, in the database (Costa *et al.* 2017; Teixeira *et al.* 2017). The results revealed some very valuable collections but the majority of species in living collections raise the concern regarding deficiencies in genetic diversity of collections.

Despite recent improvements, *ex situ* conservation of threatened species is still an overlooked issue in Brazil. This situation compromises the international conservation commitments signed to achieve the Target 8 during the remaining two-year period. Our results may have slightly underestimated *ex situ* conservation in Brazil, since some institutions did not participate in the survey and three botanic gardens did not reply to our demand. Unfortunately, the inexistence of an integrated database to compile and provide available information of plant collections hinders a more comprehensive assessment.

Our results showed significant knowledge gaps in *ex situ* conservation [Table S2 (<<https://doi.org/10.6084/m9.figshare.7199750.v2>>)]. Nearly 75% of respondents declared to have worked with seed conservation in native species. Unexpectedly however, only half of respondents (38%) were aware of the GSPC Target 8. For example, 40% of researchers had never incorporated accessions to seed banks despite having worked with seed conservation in hundreds of species. Half of the

respondents found unlikely that Brazil will achieve the Target by 2020, whereas only 13.5% thought it is possible to meet the challenge by 2020. Nearly 80% of respondents found the status of seed conservation is bad/very bad (unsatisfactory) and 64% found the status of science outreach of seed conservation to be bad/very bad. Additionally, over half of respondents was not aware of the economic costs associated to seed banking. Indeed, the survey revealed that between 60–70% of the respondents thought that seed conservation status and knowledge transfer were neglected, especially due to lack of economic and human resources, infrastructures and policy coordination.

Relative to the question about the strategies to improve the current scenario of *ex situ* plant conservation in Brazil, only 57% of respondents expressed any suggestion. Overall, four main issues were raised to pursue the achievement of the Target by 2020: (1) to prompt a coordinated effort between government and the scientific community that boosts further research, international partnerships and public policies; (2) to enhance the cooperation and communication among national conservation institutions to enable data access and sharing; (3) to increase the economic and human investment in order to upgrade the number and quality of accessions in seed banks, mainly in underrepresented biomes; and (4) to prioritize the collection of species in relation to their occurrence and threatened status, decentralizing the sampling and storage efforts through the national territory.

Brazil harbors the highest number of seed-bearing species and endemism in the world (Forzza *et al.* 2012; Brazilian Flora 2020), and it currently plays an international leading role in environmental conservation (Scarano *et al.* 2012; Crouzeilles *et al.* 2017). However, *ex situ* conservation requires a structured nationwide strategy coordinated by government agencies, policy makers and research institutions.

Target 8 is likely the most difficult GSPC target to achieve due to the time-consuming, experimental work needed to conserve species. Information on species physiology including knowledge on seed biology (production, dormancy, germination, storage) and horticultural protocols (Fig. 1, see Harding *et al.* 2013) is needed before plants or seeds can be effectively conserved in *ex situ* institutions (Costa *et al.* 2017). Unfortunately, these data are still lacking for the vast majority of native species, let alone the threatened ones (Ribeiro *et al.* 2016).

There are many challenges ahead that need to be urgently tackled if we are to steer the knowledge and conservation biases in the *ex situ* conservation of the Brazilian flora (Tab. 1). We need to reduce both the phylogenetic and geographic biases that permeate the knowledge on the seed ecology (Ribeiro *et al.* 2016). Reducing the phylogenetic bias means we need to conserve species in families other than Cactaceae, Bromeliaceae and Orchidaceae, which are the dominant in *ex situ* collections. Reducing the geographic bias means we need to safeguard threatened species from biomes other than the Atlantic Forest. As more species will become threatened in the near future (Pimm & Raven 2017), and risk assessment is carried out for more species (G. Martinelli, personal communication), the task for the future is more challenging than it is today (Tab. 1).

Large parts of the country are covered by forests which typically harbor species with recalcitrant (desiccation-sensitive) seeds which cannot be stored by convenient methods (Walters *et al.* 2013; Wyse & Dickie 2017). This implies we need to develop specific protocols for cryogenic storage (Tab. 1), especially for species from the Amazon and the Atlantic Forest.

We found different difficulties in identifying and contacting plant conservation institutions involved in conserving threatened plants. Another hurdle was to get detailed and organized information in a user-friendly and interactive manner. We urge authorities to urgently develop a national integrated database similar to that of PlantSearch by BGCI (<https://www.bgci.org/plant_search.php>). This database will contribute to the provision of organized information on plant species conserved in botanic gardens, national (*i.e.*, EMBRAPA) and regional research companies and universities. Therefore, detailed information on *ex situ* conserved threatened plant species will be available for conservation, research and educational purposes. Ultimately, this database will be used to evaluate progress toward Target 8 of the GSPC, expanding the knowledge to save and understand plant diversity (Tab. 1).

We also need to develop protocols to evaluate germplasm quality (Liu *et al.* 2018) including accurate plant identification; genetic representativeness of the species; population and individual sampled; high viability with acceptable longevity; contain sufficient germplasm to supply intended uses; and collection acquired

Table 1 – Challenges and solutions to overcome hurdles in *ex situ* conservation in Brazil.

Challenge	Why it is a problem	Proposed solutions	Reference
Knowledge gap	Prevents determination of the best <i>ex situ</i> conservation method	To use phylogenetic and functional information to improve knowledge on relevant seed traits	1, 2, 3
Phylogenetic and geographic bias	Restricts the evolutionary and functional diversity of seed banks	To sample species in undersampled areas and clades	1
Increasing number of threatened species	As more species are becoming threatened, more species need to be conserved	To implement optimized protocols for seed banking, change legislation to require <i>ex situ</i> conservation before degrading endeavors	4, 5, 6, 7
Increase genetic diversity	Poor information on genetic diversity in seed banks	To established a genetically representative <i>ex situ</i> collection	8, 9
Increase availability of seeds for restoration	Poor information available on the restoration seed pool	To bank higher number of seeds per population/species, prioritize species with higher potential for restoration, implement seed production areas	1, 10, 11
Conservation of recalcitrant seeds	Recalcitrant seeds are not amenable to traditional seed storage methods	To develop specific protocols for cryogenic storage, <i>in vitro</i> slow growth	12, 13
Data accessibility and science communication	Knowledge is restricted to academics and does not reach decision-makers	To implement on-line platform, activities of science outreach, and publications in Portuguese	14, 15

1 = Ribeiro *et al.* (2016); 2 = Wyse & Dickie (2017); 3 = Pelissari *et al.* (2018); 4 = Pimm & Raven (2017); 5 = G. Martinelli (unpub. data); 6 = Teixeira *et al.* (2017); 7 = Davies *et al.* (2016); 8 = Griffith *et al.* (2017); 9 = Oldfield (2009); 10 = Ladouceur *et al.* (2017); 11 = Broadhurst *et al.* (2017); 12 = Walters *et al.* (2013); 13 = Thormann *et al.* (2006); 14 = Amano *et al.* (2016); 15 = Doubleday & Connell (2017).

with all consents and data to facilitate intended users. Unfortunately, most information regarding germplasm quality is not readily available in our database. Assessing germplasm quality is highly relevant for restoration purposes.

GSPC Target 8 does not consider the extent of habitats that a species occupies or how collections of a particular species should be representative of the genetic diversity of that species. Thus, the collections do not necessarily hold the associated provenance, ecological and conservation information associated to the species conserved, which is essential for successful recovery and restoration programs. Species-specific efforts to increase germplasm genetic diversity (Griffith *et al.* 2017) and sufficient material are critical for plant reintroduction and restoration (Tab. 1). Emerging technologies and protocols that optimize staff time and costs, and at the same time reduce the number of seeds for testing, should be implemented to monitor viability in seed genebanks and in tissue cultures (Harding *et al.* 2013; Davies *et al.* 2016; Hay & Whitehouse 2017). Lastly, our nationwide survey has shown the need to improve data accessibility and science communication.

Brazil's progress in Target 8 can be improved if it learns from the international experience and follows the countries with more extensive work on *ex situ* conservation initiatives. For instance, the United States, France and Australia have a large number of institutions with seed banking and have strong national networks working together to conserve plant diversity (O'Donnell & Sharrock 2017). In megadiverse countries, such as South Africa, a successful National Strategy for Plant Conservation has been accomplished where taxonomists, government agencies and non-governmental organizations jointly coordinated seed banking of 35% of threatened species by 2013 (Sharrock *et al.* 2014). Mexico, in turn, proposes to conserve 100% of threatened species in botanic gardens by 2030 and 90% of them with propagation and cultivation programs.

No institution can effectively act alone in *ex situ* conservation, so integrating Brazilian institutions is major requirement that needs to be filled to promote cross-institution collaborative efforts. To strengthen the contribution of institutions to *ex situ* conservation, a national network should be established, under the steering of the MMA, as suggested by the National Center for Flora Conservation (CNCFlora) on National Strategy for *ex situ* conservation of threatened Brazilian

Flora (CNCFlora 2016). This network will increase conservation redundancy across institutions and secure against lost of accessions, especially for critically endangered species.

In 2011, Australia launched the Seed Bank Partnership and "The 1,000 species project" from a collaborative national effort to bank seeds of 80% of Australian threatened flora by 2020 (CHABG 2011). Overall, Australia and New Zealand had already banked 56% of threatened species by 2013 (Sharrock *et al.* 2014). China established the Germplasm Bank of Wild Species in 2008 from a nationwide seed-collecting network that includes 71 research institutions to store 10,000 national species in seed banks by 2020; 8,855 species were successfully banked by 2014, which represents about 30% of the country's vascular plant diversity (Cai 2015). The Mexican National Strategy for Plant Conservation embraces 22 action groups that, by 2012, had coordinated long-term seed conservation for 1,174 species (León-Lobos *et al.* 2012). Seeds of Success and the US Center for Plant Conservation are native seed collection programs coordinated by multiple USDA Agricultural Research Service seed storage facilities and partner institutions to collect threatened species and develop ecological restoration initiatives in the United States (Galbraith & Kennedy 2006; Haidet & Olwell 2015). In Europe, the European Native Seed Conservation Network (ENSCONET) operated during 2005–2009 and updated an ENSCONET Consortium in 2010, which had included 63% of threatened species in seed banks and 48% available for restoration programs by the end of 2016 (Rivière & Müller 2017).

Monitoring progress towards Target 8 at a global scale has previously been problematic due to the limited information on which species are being conserved, where, and which of these are threatened (O'Donnell & Sharrock 2017). Some countries have this information at the national level, however for megadiverse countries with a high number of threatened species and a lack of resources, Target 8 is an ambitious task. Therefore, implementing and integrating information in a national platform and contribute data to BGCI PlantSearch is of vital importance.

Resources also need to be secured to improve new collections with a design that maximizes genetic diversity and to develop and implement an *ex situ* conservation management plan for the species. Management plans include periodic assessment of seed viability, assessment of genetic diversity, acquisition of new material,

distribution to other institutions as backups and working with partners to use stored material for *in situ* conservation efforts, such as restoration programs (Fant *et al.* 2016).

Some opportunities for obtaining financial resources are emerging for the coming years. Considering the Brazilian Biodiversity Law (Law 13,123 - May 20, 2015), the Federal government will be the main beneficiary of benefit-sharing. MMA will be able to negotiate the benefit-sharing and, possibly, to indicate projects aligned with its interests of biodiversity conservation. Additionally, the recently-created PLANAVEG - National Plan for Native Vegetation Recovery (Law 8,972 - January 23, 2017) aims to expand and strengthen public policies, financial incentives, markets, good agricultural practices and other measures necessary for the recovery of native vegetation of 12 million hectares by 2030. Target 8 can be strengthened by this plan when threatened species (at least 20% of threatened species) are indicated for vegetation recovery and restoration programs. The demand for propagules (seeds, cuttings, etc.) of threatened species can reinforce *ex situ* conservation actions. We strongly suggest that the fund-raising by the MMA together with the benefits-sharing actions should also be aimed to support projects related to biodiversity conservation, mainly for *ex situ* conservation of threatened flora. Finally, we also propose that the development of other financial incentives, such as monetary environmental compensation and the payment for environmental services can be conducted to reintroduction projects with threatened species.

Below we propose a strategy for GSPC targets in 2020-2030. If Brazil is to advance in *ex situ* conservation, the actions below are strictly needed:

- To develop a national strategic framework to improve the *ex situ* conservation of threatened species;
- To identify priorities species and research priorities to improve the knowledge of threatened species;
- To expand the capacity and delivery of *ex situ* conservation as part of an integrated conservation approach to improve the effectiveness of threatened plant conservation and ecological restoration;
- To expand professional capacity for *ex situ* conservation through recruitment and specialist training;
- To develop a national information database for *ex situ* conservation;

- To establish a national network to enhance *ex situ* conservation of the threatened Flora;
- To improve the national infrastructure of seed banks;
- To establish at least one well-structured seed bank for each region of the country;
- To maintain *ex situ* collections that meet physiological, genetic and sanitary criteria of quality;
- To develop protocols for propagation, cultivation and reintroduction for threatened Brazilian Flora;
- To adopt threatened species as symbols in awareness campaigns about the need for plant conservation;
- To create mechanisms and incentives to include educational and research institutions, botanic gardens, agricultural and environmental agencies in the conservation efforts of threatened species;

Given the huge challenges for associated with the study of seed storage and cultivation of native species, Target 8 is unachievable by 2020. Therefore, we suggest the revised Target for 2020–2030 to call for at least 50 percent of threatened plant species to be included in *ex situ* collections, preferably in the country of origin, and at least 5 percent available for recovery and restoration programs. Such strategy is similar to that adopted by megadiverse South Africa, providing a more realistic scenario (Sharrock *et al.* 2014). We also recommend the development of an on-line database and protocols to assess germplasm quality and monitoring, so that *ex situ* conservation can be integrated with *in situ* strategies.

Acknowledgments

We thank all respondents to our poll and all institutions who responded with our requests. A.L.T. and M.Z. received a Post-graduate scholarship from CAPES. F.A.O.S. received a Productivity grant from CNPq and FAPEMIG.

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Editor de área: Dr. Rafael Zenni

Artigo recebido em 26/01/2018. Aceito para publicação em 13/04/2018.



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