

The contribution of botanic gardens to *ex situ* conservation through seed banking

Katherine O'Donnell*, Suzanne Sharrock

Botanic Gardens Conservation International, Descanso House, 199 Kew Road, Richmond, Surrey, United Kingdom



ARTICLE INFO

Article history:

Received 8 May 2017

Received in revised form

19 October 2017

Accepted 26 November 2017

Available online 2 December 2017

(Editor: Vernon Heywood)

Keywords:

Seed banking

GSPC

ex situ conservation

Conservation assessments

Botanic gardens

ABSTRACT

Target 8 of the Global Strategy for Plant Conservation calls for 'at least 75 per cent of threatened plant species in *ex situ* collections, preferably in the country of origin, and at least 20 per cent available for recovery and restoration programmes by 2020'.

Botanic gardens make a significant contribution to *ex situ* conservation of wild species with more than a third of plant species represented in botanic gardens collections. These collections are a combination of living collection and seed banked material. Seed banking can provide an efficient form of conservation for wild plant genetic diversity.

Information from Botanic Gardens Conservation International's (BGCI) databases (GardenSearch, PlantSearch, ThreatSearch and GlobalTreeSearch) has been analysed as well as survey data to report on global, regional and national seed banking trends.

Information from BGCI's databases indicates that there are at least 350 seed banking botanic gardens in 74 countries. In total 56,987 taxa have been banked including more than 9000 taxa that are threatened with extinction. 6881 tree species are stored in *ex situ* seed bank collections. More than half (3562) of these tree species are single country endemics and represent species from more than 166 countries.

This study suggests that institutions are increasingly conserving plant species via seed banking. However the majority of species in collections that have a conservation assessment are not threatened with extinction. This disjunction between species that are threatened and those conserved in seed banks needs to be addressed. Data from BGCI's databases can be used to enable prioritisation of threatened plant species for collection and conservation in seed banks. Further recommendations for botanic gardens involved in seed conservation are presented.

Copyright © 2017 Kunming Institute of Botany, Chinese Academy of Sciences. Publishing services by Elsevier B.V. on behalf of KeAi Communications Co., Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

1. Introduction

The Global Strategy for Plant Conservation (GSPC) was adopted by the Convention on Biological Diversity in 2002 and updated in 2010. The strategy provides the overall framework for plant conservation at the global and national level and consists of 16 output-oriented targets. Target 8 of the GSPC calls for 'At least 75 per cent of threatened plant species in *ex situ* collections, preferably in the country of origin, and at least 20 per cent available for recovery and restoration programmes by 2020' (CBD, 2010). A number of countries have developed national responses to the GSPC including Mexico, Brazil and China, while others are

implementing them through their National Biodiversity Strategies and Action Plans and many mention the GSPC in their National Reports to the CBD.

Botanic gardens (including arboreta and associated research facilities) are one of the main institutions involved in *ex situ* conservation of wild species with 30% of known plant diversity accounting for 105,634 species held in the world's botanic gardens (Mounce et al., 2017). These collections can consist of whole plants, seed or tissue cultures.

Collections conserved as seed are referred to as 'seed banked'. Seed banking as a form of conservation has traditionally been used for crop species. However, over the past two decades an increasing number of botanic gardens and other botanical institutions are establishing seed banks for the purpose of wild plant conservation (Lupton et al., 2017; Gautier, 2004; Fahey, 2013).

* Corresponding author.

E-mail address: katherine.odonnell@bgci.org (K. O'Donnell).

Peer review under responsibility of Editorial Office of Plant Diversity.

Botanic garden seed banks are also involved in the conservation of wild species that are related to crop species. An example of this is the 'Adapting Agriculture to Climate Change' project (2011–2020) (Dempewolf, 2014). Through this project the Global Crop Diversity Trust (GCDT) is currently working with Royal Botanic Garden (RBG) Kew's Millennium Seed Bank Partnership (MSBP) on securing the primary and secondary gene pool members of 29 of the world's major crops.

Seed banking involves collecting seeds from wild plants, drying and storing them in cool conditions. In order for seed collections to be of conservation value certain protocols must be adopted. The MSBP has developed seed conservation standards which represent current best practice for long term conservation of orthodox seeds (MSBP, 2015). The seed collections are then available and can be used as required for research, reintroduction, or restoration (Cochrane, 2007; Hardwick et al., 2011; Miller et al., 2016). Seed banks provide insurance against threats to plants *in situ* including habitat loss and degradation, introduction of alien species, over-exploitation, pollution, disease and climate change. Seed banking is increasingly being used as a method of conservation for a variety of reasons:

- Estimated to cost as little as 1% of *in situ* conservation
- Can represent a range of genetic diversity if harvested from a population of individuals
- Can be stored in a relatively small space
- Seeds of many species can survive for hundreds of years in conditions of low humidity and low temperature (Li and Prichard, 2009)

Many botanic gardens are contributing to the achievement of Target 8 through seed banking wild species (CBD, 2009) (Williams and Sharrock, 2010). A variety of targets have been developed by institutions and networks at the global, regional and national levels (Table 1). In mega diverse Brazil, a recent feasibility analysis concluded that by seed banking 1500 species between 2016 and 2020 Target 8 could be met and would be economically feasible (Teixido, 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. Some countries will have this information at the national level, however for mega-diverse countries with a high

number of threatened species and a lack of resources Target 8 is an ambitious task.

Within the botanic garden community are some of the world's largest and most sophisticated seed banks that work at global and national levels. For example Royal Botanic Gardens RBG Kew's Millennium Seed Bank in the United Kingdom, the Germplasm Bank of Wild Species (GBOWS) in China and RBG Sydney's Plant-Bank in Australia but, equally importantly, a wide network of small scale but very effective seed banks are conserving local plant diversity at either the national or regional level.

Botanic Gardens Conservation International (BGCI) has for the past 30 years been collating information from its network of botanic gardens. BGCI's website (<http://www.bgci.org>) currently hosts four open access databases namely GardenSearch, PlantSearch, ThreatSearch and GlobalTreeSearch. These databases provide useful tools for plant conservation, aiding the effort of botanic gardens to measure progress, identify gaps and prioritise plants for conservation action. The data contained in these four databases have been analysed along with in-depth data gathered from BGCI's network of botanic gardens related to seed banking activities.

Below, a review of the progress being made by the botanic garden community in achieving Target 8 of the GSPC and report on global, regional and national seed banking trends is presented. Recommendations for botanic gardens conserving plant species through seed banking programs are highlighted.

2. Theory/calculation

BGCI's GardenSearch (http://www.bgci.org/garden_search.php) database is an online directory containing data from botanical institutions around the world. This database includes 3379 institutions (BGCI, 2017) and is used to determine the extent and geographical spread of botanic gardens involved in seed banking.

BGCI's PlantSearch (http://www.bgci.org/plant_search.php) database is a global database of living plant, seed and tissue collections with data from over 1145 botanical institutions around the world (BGCI, 2017). PlantSearch does not hold collection information from all 3379 institutions in GardenSearch, however it does represent the most comprehensive list available of wild plant diversity that are conserved in *ex situ*-collections. PlantSearch acts as an essential tool for monitoring and reporting on progress towards Target 8 of the GSPC (Sharrock et al., 2014). PlantSearch data is used

Table 1
Examples of global, regional and national level seed bank targets.

Target 2020 targets	Main implementer	Facilitators
Global		
Double the number of threatened species in seed banks	BGCI's Global Seed Conservation Challenge (GSCC)	200 GSCC member botanic gardens
400 IUCN red listed species in 2015		
25% of the world's bankable species conserved (Kew, 2016)	RBG Kew's MSBP	MSB Partnership institutions
Regional – Multi country		
500 vascular plant species (Müller et al., 2017)	The Alpine Seed Conservation and Research Network	5 plant science institutions in 4 countries (France, Switzerland, Italy, Austria)
National		
60% of Korea's native plant species (Choi et al., 2017)	Korea National Arboretum	
75% of Australia's threatened species (excluding orchids) (Australian Seed Bank Partnership, 2014)	Australian Seed Bank Partnership	12 botanic garden and plant conservation institutions
10,000 China's native taxa (Cai, 2015)	Germplasm Bank of Wild Species Kunming Institute of Botany, Chinese Academy of Sciences	71 organisations including botanic gardens, nature reserves and universities
75% threatened plant species Botnischer Garten & Botanisches Museum Berlin (2015)	The Dahlem seed bank at the Botanic Garden and Botanical Museum Berlin	
Regional – Sub country		
100% of the California flora (Meyer, 2015)	California Plant Rescue Project	Conservation organisations, botanic gardens and seed banks
75% of the regions threatened species conserved in seed banks or living collections New England Wild Flower Society (2017)	New England Wild Flower Society	

to determine how many species are represented in seed bank collections and to provide trend data over time.

BGCI's ThreatSearch (http://www.bgci.org/threat_search.php) is the most comprehensive database of conservation assessments in the world. Published red list conservation assessments of plant species (including the IUCN Red List of Threatened Species, national red lists and other sources) were compiled in this database that currently contains over 240,000 conservation assessments, representing over 150,000 taxa (Sharrock and Rivers, 2017). ThreatSearch was developed to act as a one-stop shop to find the conservation assessment of plant taxa. Data has been analysed to determine how many species in the seed bank have a conservation assessment and their threat status.

BGCI's GlobalTreeSearch (http://www.bgci.org/global_tree_search.php) contains over 60,000 tree species names representing all known tree species and their country-level distribution data (BGCI, 2017). GlobalTreeSearch data is used to provide information on which tree species are conserved as collections in seed banks. Also reported is the proportion of country-level endemic trees conserved in seed banks at the global and national levels.

3. Results

There are 370 institutions around the world that collect and bank seed of wild species in 74 different countries (BGCI, 2017a) (Fig. 1). There are a variety of different institutions involved with the majority (316) being botanic gardens and arboreta. Other institutions include standalone seed banks (the National Tree Seed Centre in Canada) university research facilities; (Universidad Politécnica de Madrid Seed Bank) networks (United States run Seeds of Success programme and the National Plant Germplasm System). Additionally, some research institutes conserve seed including the Tropical Forest Research Institute, India.

The majority of botanic gardens and arboreta involved in seed banking are located in Europe and the United States. The number of seed banks per country is not even. Several countries including the United States, Australia, and France have more than 20 institutions involved in seed conservation. However, for the majority of countries, only one or two institutions are involved in seed banking for wild plants. Based on analysis of geographic patterns of plant

diversity; South America, Central Africa and South East Asia were highlighted as the main regions with high plant diversity but limited seed banking activity (Fig. 2).

The seed bank collections in PlantSearch represent 56,987 distinct plant taxa of which two thirds are stored at a single institution (Fig. 3). Seed bank collections within an institution range from 18 to over 37,000 species (BGCI, 2017).

The number of taxa in PlantSearch has increased by around 18,000 since 2015. This represents an increase in the number of plant species being brought into seed bank collections but also an increase in the number of institutions adding seed bank collection data to PlantSearch. The number of institutions contributing seed bank data to PlantSearch has increased from 29 institutions in 2015 to 65 in 2017.

Of the species represented in seed bank collections, 50% (28,735) have a conservation assessment either at the global level or national/regional level (Fig. 4) (BGCI, 2017). Of the species that have a conservation assessment, 34% (9696 taxa) of these are threatened at the national, regional or global levels. If conservation assessments were available for all the species conserved in seed banks the total proportion of threatened taxa could range from 17% (if all remaining species are not threatened) to 67% (if all remaining species were threatened). An additional 499 species are regionally or globally extinct in the wild.

Currently, around 10,000 tree species are known to be threatened with extinction. Threats include land clearance and habitat degradation and unsustainable exploitation of species (Rivers et al., 2015). Cross-referencing GlobalTreeSearch with PlantSearch data suggests that 6881 tree species are represented in *ex situ* seed bank collections (BGCI, 2017). Analysis of how many of the tree species in seed bank collections are threatened suggests that less than 20% are globally or nationally threatened.

More than half of the trees species in GlobalTreeSearch (58%) are single country endemics. The number of endemic tree species at the national level ranges from 1 to 4330 in Brazil (Beech et al., 2017). 166 countries have at least one of their endemics tree species conserved in a seed bank (Fig. 5.). Of the 34,574 endemic tree species 3308 are found in botanic garden seed bank collections. 32 countries have more than 20% of their endemic tree species conserved in seed banks, 5 have 75% or more.

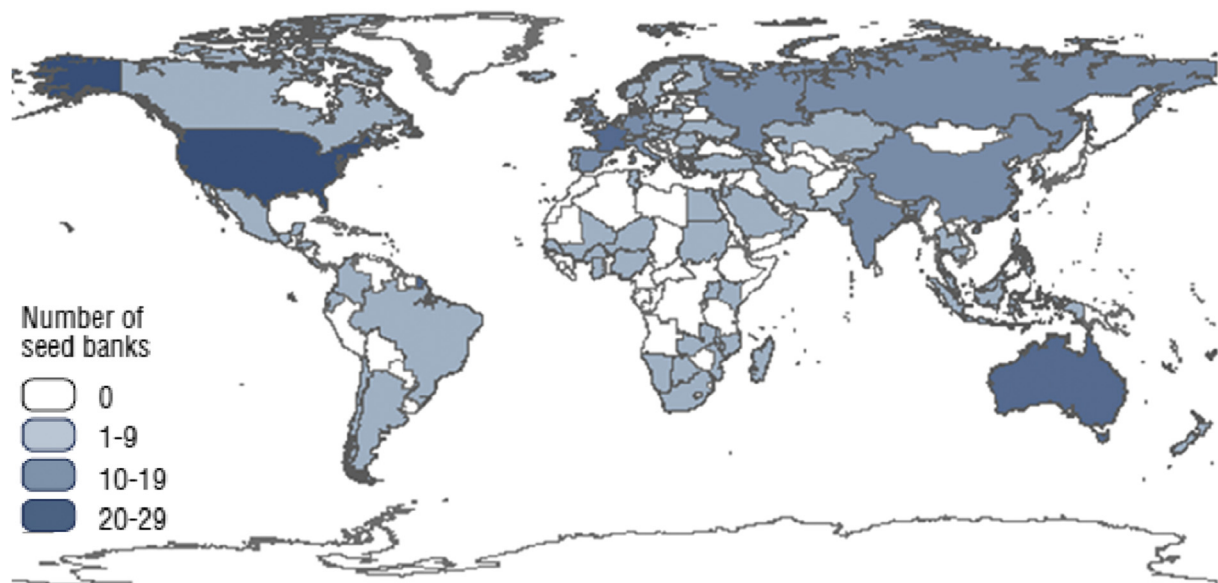


Fig. 1. Number of seed banks per country.

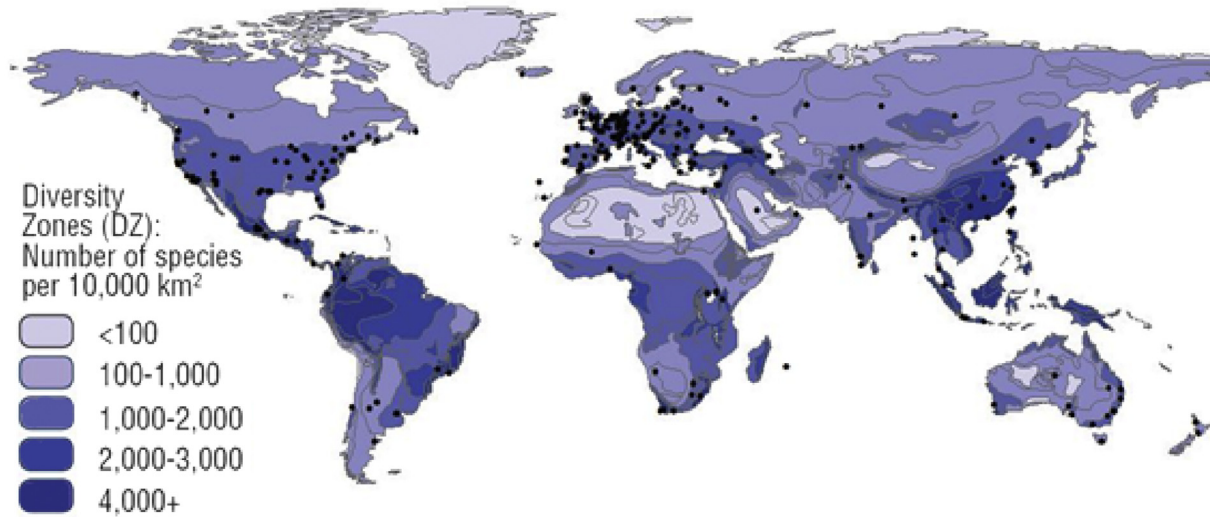


Fig. 2. The location of seed banking institutions (black dots) in relation to plant diversity (Adapted from: Kier et al., 2005).

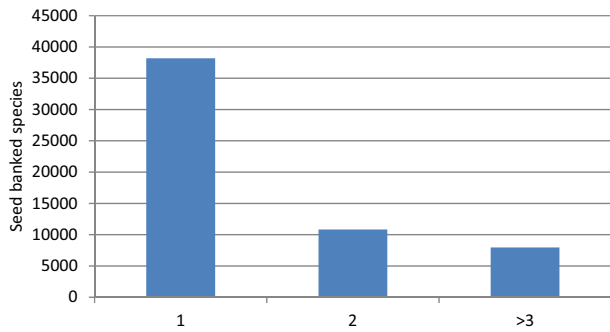


Fig. 3. Number of seed banked species held in one, two or three institutions.

Nearly 57,000 taxa are conserved as seed, accounting for over half of the diversity known to exist in botanic garden collections. Our dataset included 37,000 taxa that are held in the Millennium Seed Bank (MSB) at Kew's Wakehurst Place (Royal Botanic Gardens, Kew, 2017). The MSB plays a key role in *ex situ* conservation of wild species and aims for 25% of bankable plant species to be conserved by 2020. An additional 20,000 taxa are being conserved by other seed banking institutions around to world, highlighting the contribution of the community as a whole.

The United States, France and Australia have a large number of institutions seed banking and have strong national networks working together to conserve plant diversity as seed (Haidet et al., 2013; Bardin and Bourd, 2015; Australian Seed Bank Partnership, 2014). However our analysis suggests that at the regional level there are major gaps in capacity in regions where plant diversity is high including South America and South East Asia. This lack of capacity may be explained by the focus of seed banking in more arid environments (Slageren, 2003) and that botanic gardens are disproportionately found in temperate climates (Mounce et al., 2017). Wetter habitats were previously thought to have a high percentage of recalcitrant species; however recent research

4. Discussion

The global botanic garden community has made huge progress in the conservation of plant species through seed banking. The data presented suggests that at least 1 in 10 botanic gardens are banking seed. More than double the number of institutions that were banking seed 20 years ago (Laliberté, 1997).

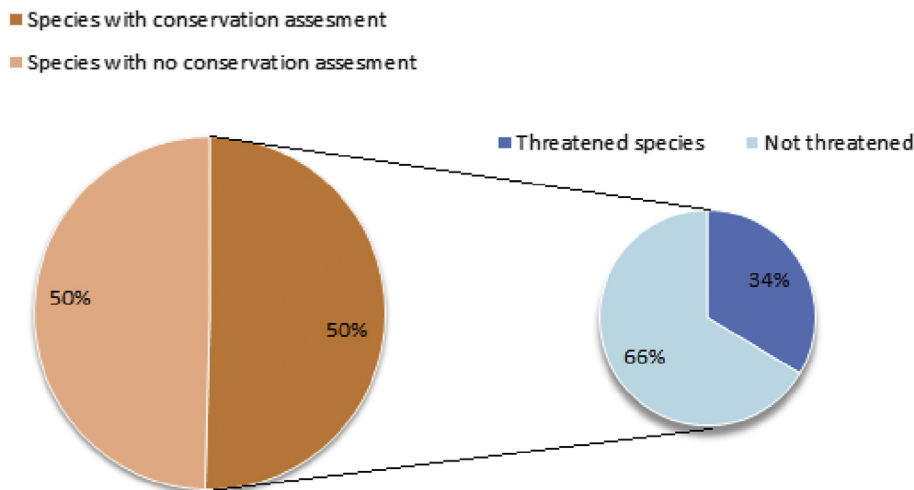


Fig. 4. Conservation status of seed bank species.

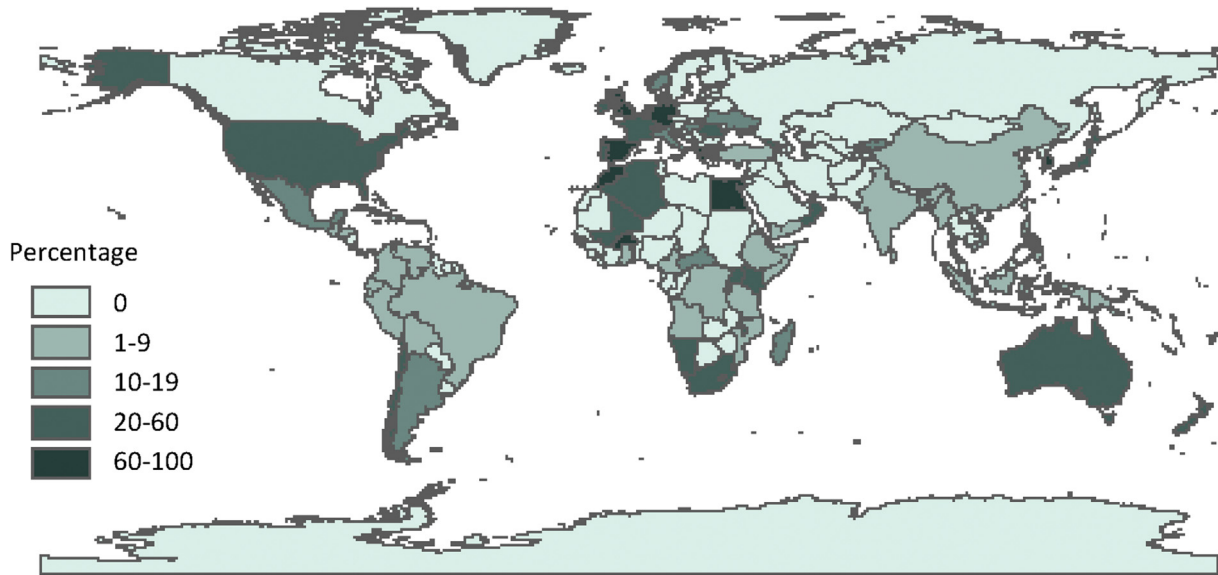


Fig. 5. Percentage of endemic tree species in seed bank collections.

estimates that desiccation tolerance could be present in more than 80% of seed-plant species (Wyse and Dickie, 2017). Therefore seed banking may be a more realistic form of plant conservation for tropical and subtropical regions than was previously thought.

Ideally, seeds should be conserved in the country of origin so that they are easily available for restoration and reintroduction. However, many countries do not have the capacity to collect and store wild collected seeds. Only 74 countries have botanic garden seed banks. If countries had to rely on national capacity for conservation, the number of species conserved *ex situ* would be much lower than it currently is. Seed of endemic trees has been collected and stored for species in 166 countries. Institutions such as RBG Kew, work with partners around the world through the MSBP to collect and bank seed that may not be duplicated in the country of origin. The Dahlem seed bank at the Botanic Garden and Botanical Museum Berlin collects seed, mainly from Germany but also from the Caucasus and Mediterranean region and the Boyce Thompson Arboretum has a programme to conserve legumes from the world's drylands.

If seed collections are to be of conservation value and use, the protocols used for banking must be of a high standard. The conservation quality of the seed bank collections found in PlantSearch has not been analysed. One standard however is for seed collections to be duplicated at a second, geographically separate, facility (MSBP, 2015). Therefore if one of the collections is destroyed, a back-up is available. Results from this analysis suggest that the majority of seed bank collections are only stored in one institution, therefore not meeting this particular standard. Further analysis is required to determine what percentage of seeds held in botanic garden seedbanks meet full conservation standards.

GSPC Target 8 is an ambitious target, constrained by a lack of information on the threat status of plants. Conservation assessments (or Red List Assessments) help to determine which species are at greatest risk of extinction. Such assessments are produced continually; therefore prioritisation for collection must run in parallel to conservation assessments. The majority (66%) of species in the seed banks, for which conservation assessment are available, were found not to be threatened. The lack of threatened species in seed bank collections may be the result of information on threat status not being as easily accessible as it currently is. BGCI's databases allow for ready identification of endemic and threatened

plants in collections, as well as conservation priority setting through the identification of gaps in collections. However constraints to collection of threatened species may also include; lack of resources for fieldwork, especially when population fruiting time is sporadic or data is unavailable and species are found in remote areas. Institutional funding may be dependent on the number of species rather than the conservation priority of the species. Opportunistic collection, where species may not be the priority for collection but are collected anyway as they are fruiting may also be an explanation.

Only 10% of endemic tree species are represented in botanic garden seed bank collections. However 32 countries have more than 20% of their endemic tree species in seed bank collections. It has been shown that at the country level, endemic tree species not in a seed bank collection can be identified and prioritised for collection.

Seed banks provide an important role to the conservation of species that are extinct in the wild. Close to 500 taxa that were identified as either regionally or globally extinct in the wild are conserved as *ex-situ* seed collections.

Recommendations

If seed banks are to be a useful tool for conservation, the number of threatened species that are conserved needs to increase. Botanic gardens need to prioritise threatened species for collection and use existing collections, especially those that are extinct in the wild. In addition the conservation quality of the seed bank collections needs to be assessed.

National and regional strategies towards Target 8 of the GSPC should be adopted in countries where capacity for seed banking exists, working with national networks of botanic gardens and other institutions to collect seed.

Data stored in BGCI's databases can be used to identify gaps in collections and prioritise seed collection of species that are known to be threatened with extinction.

Currently only 1 in 5 seed banking institutions add data to PlantSearch. Institutions involved in *ex situ* conservation of wild plants (both living plant collections and seed banks) should share data via BGCI's PlantSearch database. This data will be used to

facilitate coordination towards Target 8 of the GSPC as well as to monitor and report on progress.

Botanic gardens should duplicate accessions at other institutions, either by creating links with agricultural gene banks in country or other institutions out with the country of origin.

Conclusions

Seed banking is increasingly being used to conserve rare and threatened plant species, ensuring that material of such species is available for recovery, reintroduction and restoration programmes. There has been a significant increase in the number of botanic gardens with seed banks in recent years and the number of seed banked taxa recorded in PlantSearch has increased dramatically. BGCI's databases provide a unique tool to identify gaps in collections of threatened species, the more data they contain the better informed conservation actions will be.

References

- Australian Seed Bank Partnership, 2014. Safeguarding Australia's flora through a national network of native plant seed banks. In: The Council of Heads of Australian Botanic Gardens Incorporated, 9.
- Bardin, P., Bourd, S., 2015. Designing seed banks for in-situ conservation purposes: more species or better quality. *BGjournal* 12 (1), 15–18.
- Beech, E., Rivers, M., Oldfield, S., Smith, P., 2017. GlobalTreeSearch – the first complete global database of tree species and country distributions. *J. Sustain. For.* 36 (5), 454–489.
- BGCI, 2017a. GardenSearch Online Database. Botanic Gardens Conservation International, Richmond, U.K. Available at: https://www.bgci.org/garden_search.php. (Accessed 28 April 2017).
- BGCI, 2017b. GlobalTreeSearch Online Database. Botanic Gardens Conservation International, Richmond, U.K. Available at: https://www.bgci.org/global_tree_search.php. (Accessed 28 April 2017).
- BGCI, 2017c. PlantSearch Online Database. Botanic Gardens Conservation International, Richmond, U.K. Available at: www.bgci.org/plant_search.php. (Accessed 28 April 2017).
- BGCI, 2017d. ThreatSearch Online Database. Botanic Gardens Conservation International, Richmond, U.K. Available at: https://www.bgci.org/threat_search.php. (Accessed 1 March 2017).
- Botanischer Garten & Botanisches Museum Berlin, 2015. Saatgutbank Dahlem Seed Bank. BGBM Press.
- Cai, J., 2015. Seed conservation of China's flora through the germplasm bank of wild species. *BGjournal* 12 (1), 22–24.
- CBD, 2009. The Convention on Biological Diversity Plant Conservation Report: a Review of Progress in Implementing the Global Strategy for Plant Conservation (GSPC), pp. 1–48.
- CBD, 2010. Conference of the Parties 10 Decision X/17. Consolidated Update of the Global Strategy for Plant Conservation 2011–2020. Secretariat of the Convention on Biological Diversity. <https://www.cbd.int/doc/decisions/cop-10/cop-10-dec-17-en.pdf>.
- Choi, G.E., Ghimire, B., Lee, H., Suh, G.U., Son, S.W., Jeong, M.J., Lee, C.H., 2017. Ex situ seed conservation of rare plants in South Korea: a key role of seed bank, Korea National Arboretum. In: Presented at the 6th Global Botanic Garden Congress, Geneva.
- Cochrane, J.A., Crawford, A.D., Monks, L.T., 2007. The significance of ex situ seed conservation to reintroduction of threatened plants. *Aust. J. Bot.* 55 (3), 356–361.
- Dempewolf, H., Eastwood, R.J., Guarino, L., Khoury, C.K., Müller, J.V., Toll, V., 2014. Adapting agriculture to climate Change: a global initiative to collect, conserve, and use crop wild relatives. *Agroecol. Sustain. Food Syst.* 38 (4), 369–377.
- Fahey, M., Martyn, A., Offord, C., 2013. Historic seed collections germinated for the Australian PlantBank opening. *Australasian plant conservation. J. Aust. Netw. Plant Conserv.* 22 (3), 7–8.
- Gautier, C., 2004. Seed bank of threatened plants in the 'Conservatoire Botanique National de Brest' (France). *Scripta Botanica Belgica* 29, 119–120.
- Hardwick, K.A., Fiedler, P., Lee, L.C., Pavlik, B., Hobbs, R.J., Aronson, J., Bidartondo, M., Black, E., Coates, D., Daws, M.I., Dixon, K., Elliott, S., Ewing, K., Gann, G., Gibbons, D., Gratzfeld, J., Hamilton, M., Hardman, D., Harris, J., Holmes, P.M., Jones, M., Mabberley, D., Mackenzie, A., Magdalena, C., Marrs, R., Milliken, W., Mills, A., Lughadha, E.N., Ramsay, M., Smith, P., Taylor, N., Trivedi, C., Way, M., Whaley, O., Hopper, S.D., 2011. The role of botanic gardens in the science and practice of ecological restoration. *Conserv. Biol.* 25 (2), 265–275.
- Haidet, M., Kwong, O., Olwell, P., 2013. Seeds of Success: seed banking and native plant materials for a changing climate. In: Presented at the 6th Global Botanic Garden Congress, Geneva.
- Kier, G., Mutke, J., Dinerstein, E., Ricketts, T.H., Küper, W., Kreft, H., Barthlott, W., 2005. Global patterns of plant diversity and floristic knowledge. *J. Biogeogr.* 32 (7), 1107–1116.
- Laliberté, B., 1997. Botanic garden seed banks/genebanks worldwide, their facilities, collections and network. *Bot. Gard. Conserv. News* 9 (1), 18–23.
- Li, D., Prichard, H.W., 2009. The science and economics of ex situ plant conservation. *Trends Plant Sci.* 14 (11), 614–621.
- Lupton, D., Al Moqbali, H., Al Rahaili, B., Al Qassabi, Z., Al Hajri, B., Anderson, A., Patzelt, A., 2017. The Oman Botanic Garden (3): a review of progress (2010–2016) with emphasis on herbarium and seed bank collections, propagation challenges and garden design principles. *Sibbaldia* 14, 119–132.
- Meyer, E., 2015. Increasing ex situ conservation efforts in California. *BGjournal* 12 (1), 9–11.
- Mounce, R., Smith, P., Brockington, S., 2017. Ex situ conservation of plant diversity in the world's botanic gardens. *Nat. Plants* 3, 795–802.
- MSBP, 2015. Seed Conservation Standards for 'MSB Partnership Collections'. http://www.kew.org/sites/default/files/MSBP%20Seed%20Conservation%20Standards_Final%2005-02-15.pdf. (Accessed 4 May 2017).
- Miller, J.S., Lowry, P.P., Aronson, J., Blackmore, S., Havens, K., Maschinski, J., 2016. Conserving biodiversity through ecological restoration: the potential contributions of botanical gardens and arboreta. *Candollea* 71, 91–98.
- Müller, J.V., Berg, C., Détraz-Méroz, J., Erschbamer, B., Fort, N., Lambelet-Haueter, C., Margreiter, V., Mombrial, F., Mondoni, A., Pagitz, K., Porro, F., Rossi, G., Schwager, P., Breman, E., 2017. The Alpine seed conservation and research network – a new initiative to conserve valuable plant species in the European Alps. *J. Mt. Sci.* 14, 806–810.
- New England Wild Flower Society, 2017. Strategic Plan 2017–2021.
- Rivers, M., Shaw, K., Beech, E., Jones, M., 2015. Conserving the world's most threatened trees. In: A global Survey of *Ex Situ* Collections. BGCI.
- Royal Botanic Gardens, Kew, 2017. The international newsletter of the Millennium seed bank partnership. *Samara* 31, 16.
- Sharrock, S., Rivers, M., 2017. Red lists: plant conservation assessments and the role of botanic gardens. *BGjournal* 14 (1), 2–4.
- Sharrock, S., Oldfield, S., Wilson, W., 2014. Plant Conservation Report 2014: a Review of Progress towards the Global Strategy for Plant Conservation 2011–2020, p. 32. CBD Technical Series No.81.
- Van Slageren, M.W., 2003. The Millennium Seed Bank building partnerships in arid regions for the conservation of wild species. *J. Arid Environ.* 54, 195–201.
- Teixido, A.L., Toorop, P.E., Liu, U., Ribeiro, G.V.T., Fuzessy, L.F., Guerra, T.J., Silveira, F.A.O., 2017. Gaps in seed banking are compromising the GSPC's Target 8 in a megadiverse country. *Biodivers. Conserv.* 26 (3), 703–706.
- Williams, S., Sharrock, S., 2010. Botanic gardens and their response to the global strategy for plant conservation. *BGjournal* 7 (2), 3–7.
- Wyse, S.V., Dickie, J.B., 2017. Predicting the global incidence of seed desiccation sensitivity. *J. Ecol.* 105 (4), 1082–1093.

Further reading

- Hoban, S., Schlarbaum, S., 2014. Optimal sampling of seeds from plant populations for ex-situ conservation of genetic biodiversity, considering realistic population structure. *Biol. Conserv.* 177, 90–99.
- Linington, S., Way, M., 1997. The Millennium seed bank project. *BSBI News* 74, 15–16.
- Rivers, M., 2017. The Global Tree Assessment – red listing the world's trees. *BGjournal* 14 (1), 16–19.
- Ross, M., Smith, P., Brockington, S., 2017. Ex situ conservation of plant diversity in the world's botanic gardens. *Nat. Plants* 3, 795–802.
- Royal Botanic Gardens, Kew, 2015. A global resource for plant and fungal knowledge. *Sci. Strategy* 2015–2020.