Biological Conservation 281 (2023) 109991

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Perspective

Using stored seeds for plant translocation: The seed bank perspective

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ARTICLE INFO

Keywords:
Ex situ conservation
GSPC Target 8
Literature review
Questionnaire
Seed bank

ABSTRACT

Billions of seeds from wild species are currently stored in hundreds of conservation seed banks around the world. Plant translocation from these seeds is a key conservation priority and one of the targets of the UN's Global Strategy for Plant Conservation. How these seeds are used for plant translocation and what obstacles seed banks encounter has not been investigated. To explore this issue, we circulated a questionnaire across international networks, complemented with a literature review on plant translocation from stored seeds. We received responses from 104 seed banks in 34 countries. Just over 70 % had previously used their collections for plant translocation, with a median of 12 translocations per seed bank. The main limitations for translocation were identified as "funding" and "resources", with a lack of seeds and expertise also mentioned as obstacles. Only 11 seed banks had no constraints on their ability to carry out plant translocation. With 96 % of respondents indicating they would like to carry out future plant translocations, there is a willingness by seed banks to use their collections more extensively, but a lack of funding and resource availability is limiting the full potential for translocation activities. The literature review identified 12 articles which specified that seed bank stored seeds were used for plant translocation, suggesting that plant translocations from ex situ seeds are rarely published in the scientific literature. Our results indicate that if nations are to achieve their international conservation targets, funding and resources for the use of banked seeds should be prioritised.

1. Introduction

Biodiversity loss is a growing global problem, accelerated by habitat destruction and climate change (Secretariat of the Convention on Biological Diversity, 2020). For plants, ex situ conservation provides an insurance policy for species that are vulnerable to population decline or extinction. Ex situ collections are becoming increasingly important as habitat loss is leading to an increase in the number of species threatened with extinction (IPBES, 2019). On the IUCN Red List there are almost 25,000 wild plant species categorised as threatened (either Critically Endangered, Endangered, Vulnerable or Extinct in the Wild; IUCN, 2022). To mitigate this situation, the UN developed a Global Strategy for Plant Conservation (GSPC) with 16 targets, including the ex situ storage of seeds for long-term conservation. Target 8 aims to ensure that at least 75 % of threatened plant species are stored ex situ, with a minimum of 20 % of these species available for plant recovery and restoration (GSPC, 2012). For plants, this recovery is typically in the form of conservation translocation, defined as the deliberate movement of organisms from one location to another, where the primary objective is to benefit species conservation (IUCN, 2013). A recent progress review of the GSPC revealed limited success for Target 8, suggesting there are challenges with plant translocation from stored seeds (Sharrock, 2020).

The natural desiccation-tolerance of orthodox seeds has been exploited to enable long term ex situ storage for many years under cold conditions (−18 °C) after drying seeds to 15 % equilibrium relative humidity (FAO, 2014). Historically, seed banks were associated with agriculture, and have been used for many years with the purpose of preserving crop diversity, ensuring food security, and improving crop varieties (Hay et al., 2021). With the emerging concerns of diminishing plant diversity, seed banks focusing on conserving wild plant species are a major tool in plant conservation. One of the most important seed banks for the global conservation of wild species is the Millennium Seed Bank

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https://doi.org/10.1016/j.biocon.2023.109991
Received 24 October 2022; Received in revised form 13 February 2023; Accepted 23 February 2023
Available online 6 March 2023

(MSB) located in the United Kingdom. With 2.4 billion seeds of approximately 40,000 species, it is the largest seed bank in the world (Millennium Seed Bank, 2022a). The MSB Partnership, which has banked more than 10 % of orthodox seeded species, has links with almost 100 countries and focuses on protecting plant biodiversity to help meet the aims of the GSPC Target 8 (Liu et al., 2018). Another large seed bank specifically for wild plant conservation is the Germplasm Bank of Wild Species in Kunming, China which stores seeds from over 11,000 species (Breman et al., 2021) and aims to protect the highly endemic and threatened Chinese flora (Cai, 2015). Additionally, there are several networks that are working at a regional scale to conserve plant diversity ex situ, for example the European Native Seed Conservation Network (ENSCONET; Rivière and Müller, 2018), the Australian Seed Bank Partnership (Sutherland, 2012) and the US Center for Plant Conservation network (Galbraith and Kennedy, 2006). As well as contributing seeds and plants for recovery and restoration programmes, seed banks carry out research on dormancy breaking requirements and study seed behaviour, longevity and viability in storage, important traits for successfully producing plants from stored seeds (O'Donnell and Sharrock, 2018). Whilst there are crop gene banks and wild species seed banks, the two typically have differing objectives when it comes to plant translocation activities. Both aim to conserve genetic diversity, with wild species seed banks focussed on population reinforcement or introduction of new populations, whilst agricultural gene banks aim to safeguard crop species and crop wild relatives for breeding programmes and crop optimisation.

The seeds that are stored in the world's seed banks have great potential to be used for in situ conservation projects. Plant translocation can be in the form of reinforcement, reintroduction, and conservation introduction (i.e., assisted colonisation or ecological replacement), with the aim of improving the conservation status of a species or restoring habitat to benefit ecosystem functioning (IUCN, 2013). Although plant translocation activities are increasingly used in conservation action plans, little is known about the contribution of seed banks to plant translocation activities. This is important because seed banks need to demonstrate their usefulness in plant conservation to continue receiving funding and/or successfully apply for additional funds. The advantages of using seed banks for conservation are that seeds of wild species remain viable for many decades under proper storage conditions so can be used over many years for plant translocation activities (Solberg et al., 2020); wild populations do not have to be resampled, thereby reducing the risk of overharvesting; and seed banks are very space efficient allowing thousands of species to be stored within only a few square metres (Millennium Seed Bank, 2022a). Moreover, as ex situ collections in seed banks are frozen and hence are only rarely regenerated under artificial conditions, they do not suffer from genetic erosion or adaptive changes, unlike living collections in botanic gardens (Ensslin et al., 2015; Ensslin and Godefroid, 2020). However, there are potential disadvantages in using seed banking as a tool for conservation. For example, small collections can limit the use of seed material for translocation activities and some species produce recalcitrant (desiccation sensitive) seeds which are not suitable for long term storage under standard seed bank conditions (Wyse and Dickie, 2017). Additionally, as seeds stored in seed banks do not experience the natural environment, translocation back to a site that has been altered by environmental changes may mean the habitat is no longer suitable for the target species (Ensslin et al., 2015).

With ex situ seed storage an increasing priority for plant conservation, it is timely to consider how seed banks use their collections for plant translocation and identify any challenges they face. As our study aims to explore the contribution of banked seed collections to plant translocation of wild species, we have focused on seed banks mainly involved with wild species rather than crops. Seed banks are in a unique position to contribute to plant translocation for conservation as they have the source material, particularly important for extinct in the wild species, and experienced personnel to assist with translocation activities (Breman et al., 2021). Although most seeds are long lived in ex situ storage, they inevitably lose viability over time (Rajjou and Debeaujon, 2008). Therefore, it is important that wild species seed banks do not act solely as an ex situ storage facility for seeds but actively contribute to in situ conservation efforts before there is loss of seed viability. This includes donating seeds and providing expertise to other organisations that perform translocations. Once a species has become extinct in the wild it is very difficult to reintroduce (Abeli et al., 2020) and seed banks are well placed to support plant conservation before this occurs. In this study we aim: 1) to identify how seed banks are utilising their collections to support plant translocation via a questionnaire distributed to the global seed bank community; and 2) to establish whether plant translocations from stored seeds are considered in applied research by reviewing the peer-reviewed scientific literature. Based on the reported limited progress made towards Target 8 (Sharrock, 2020), we expect that collections within seed banks are not fully utilised. We also expect to find a small number of scientifically published articles that have used seed bank stored seeds for plant translocation. We hope this perspective will contribute to a better understanding of plant translocation from ex situ stored seeds, and, by highlighting the obstacles seed banks experience, help to inform future conservation projects.

2. Materials and methods

2.1. Questionnaire

A short, semi-structured questionnaire was created using Google Forms to collect information about seed banks, including the resources they have available, translocations performed, limitations when utilising their collections, and future translocation aspirations (Appendix A). The questionnaire was circulated amongst major seed banking networks around the world, including the EU COST Action CA18201 'An integrated approach to conservation of threatened plants for the 21st Century (ConservePlants)' group (https://www.cost.eu/actions/CA18201/), the Australian Seed Bank Partnership (https://www.seedpartnership.org.au), the European Native Seed Conservation Network (ENSCONET; http://www.ensconetconsortium.eu), the IUCN Seed Conservation Specialist Group (https://seedconservationsg.org), Botanic Gardens Conservation International (BGCI; https://www.bgci.org), the Millennium Seed Bank Partnership (MSBP; https://www.kew.org/science/our-science/projects/banking-the-worlds-seeds), and through social media and personal contacts. The email accompanying the questionnaire explained its rationale and emphasised the desire to receive responses from all wild species seed banks, regardless of plant translocations already performed (Appendix B). All graphs were created in the R statistical environment version 4.1.3 (R Core Team, 2022) using the package ggplot2 (Wickham, 2016) with colour-blind friendly palettes from RColorBrewer (Neuwirth, 2022).

2.2. Literature review

To determine if plant translocations from stored seeds are published in the scientific literature, a search was carried out in November 2022 on the Web of Science and Scopus databases using the keywords "plant translocation" OR "plant reintroduction" OR reintro* OR re-intro* OR "seed bank" AND seed*. The results of these searches were combined and duplicates removed. Articles from non-peer reviewed sources (e.g. book chapters) were excluded. Publications that used fresh seeds (i.e. not dried then stored under standard seed bank conditions), plants produced from fresh seeds, or those where the origin of the seeds was unclear were excluded from the final list of publications.

3. Results

3.1. Questionnaire

Questionnaire responses were received from 104 seed banks in 34 countries. Most of the respondents were from Europe and North America (Fig. 1). The majority of seed banks (72 %) had previously carried out plant translocations using their collections, with a median of 12 translocations per seed bank. There were regional variations in the number of translocations performed, with seed banks in North America and Australia having carried out almost three times more plant translocations compared to Europe and Asia (Fig. 1b). Most respondents had performed fewer than ten translocations (Fig. 2a). Moreover, in most cases, seed banks store seeds no longer than five years before they use them for translocation (Fig. 2b).

The primary purposes of the seed banks that responded to the questionnaire were, in descending order: long-term conservation of wild species (81 %); research (63 %); short-term conservation for use (56 %); and long-term conservation of crop species (21 %). Seed banks that had performed plant translocation were more likely to have their primary purpose as long-term conservation of wild species, short-term conservation for use, and research (Appendix C, Table S1). Most seed banks were involved in research activities, mainly related to conservation (86 %) and seed science and ecology (61 %). Seed banks that had already performed plant translocation were more research active with only 3 % not undertaking any research activity compared to 14 % of seed banks that had not carried out translocation (Appendix C, Table S1). Just over half of seed banks (58 %) were associated with a botanic garden, 36 % with a university and 22 % with another research institute; most were publicly funded (62 %), with the remainder privately funded (13 %) or receiving both private and public financing (23 %). Seed banks that had carried out plant translocations were more often associated with a botanic garden or university and were both publicly and privately funded (Appendix C, Table S2). Most seed banks regularly apply for funding (63 % every other year or more) but a considerable number apply only once in five years (22 %) or never (15 %), with no major differences between seed banks that had performed plant translocation and those that had not (Appendix C, Table S2).

Of the seed banks that had performed translocations, 87 % could quantify the success but data on the translocation outcome was not readily available for 66 % (Appendix C, Table S3). For seed banks that had done no translocations, the main reasons were the number of seeds available was too small (45 %), translocation was not in the seed bank's remit (31 %) or there was no resource available (28 %). In addition, 45 % of respondents also indicated other reasons as to why translocation had not been performed, with the most common being there was no requirement or request to perform plant translocation from their collections and the seed bank had only recently been established (Appendix C, Table S4). The resources seed banks had available for propagating plants from seeds were, in descending proportion: outdoor space for cultivation and/or acclimatisation (84 %); propagation greenhouses (78 %); incubators (77 %); and staff to assist with germination and propagation (62 %). A larger percentage of those that had already carried out plant translocation had incubators and propagation greenhouses available compared to those that had not performed translocation (Appendix C, Table S5).

All seed banks were asked about their constraints for plant translocation, of which 64 % identified funding, 55 % said resources (staff, equipment, time) and 17 % lacked expertise. For those seed banks that had already performed translocation, a higher percentage identified funding and resources as limitations compared to seed banks that had not performed translocation (Fig. 3; Appendix C, Table S6). For those seed banks that mentioned other constraints, the most common was that plant translocation was not a priority for the seed bank, there were too few seeds available and there were legal difficulties with carrying out plant translocation in protected areas. Only 11 out of 104 seed banks responded that they had no constraints on using their collections for translocation. The overwhelming majority (96 %) of seed banks

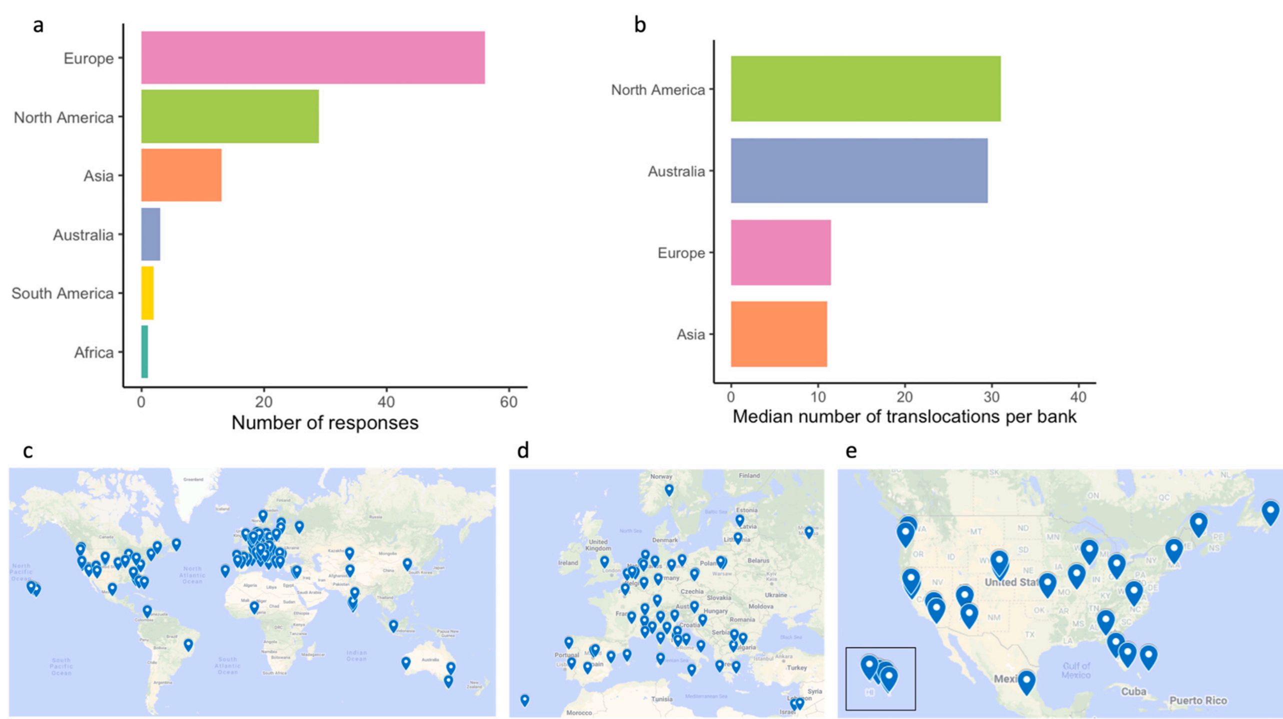

Fig. 1. Global distribution of questionnaire responses. a – Bar plot with the number of responses received from each continent; b – bar plot with the median number of translocations per seed bank for each continent, excluding South America and Africa as there was only one seed bank that had performed translocation for these continents; c – map showing global distribution of responses; d – map showing European distribution of responses; e – map showing North American distribution of responses. All maps were created using Google My Maps (https://mymaps.google.com).

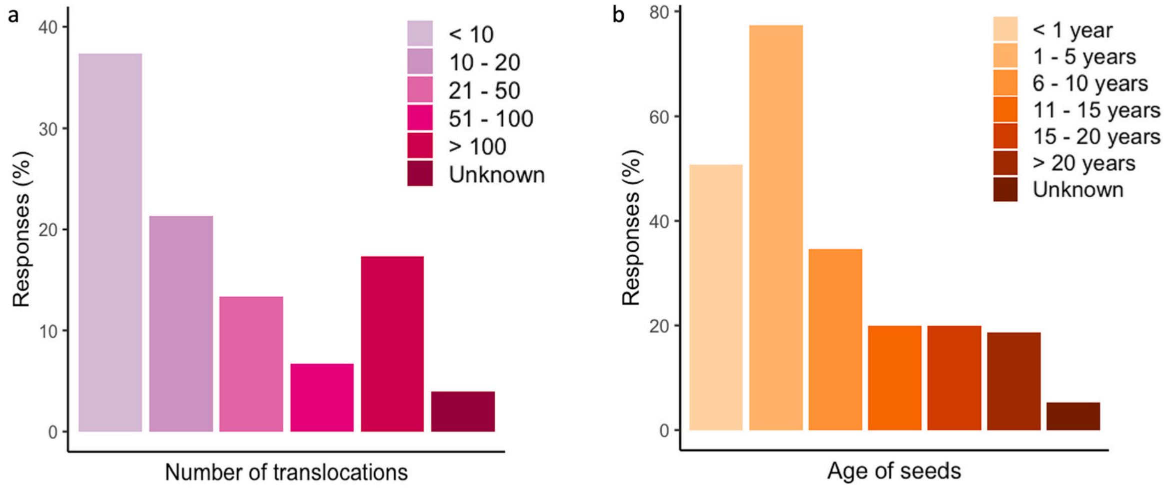

Fig. 2. Plant translocations performed by seed banks. a – Percentage of the responses for the number of translocations performed by seed banks; b – percentage of the responses of the age of the seeds used in plant translocations. The question regarding the age of the seeds allowed for multiple answers so the total percentage is over 100 %.

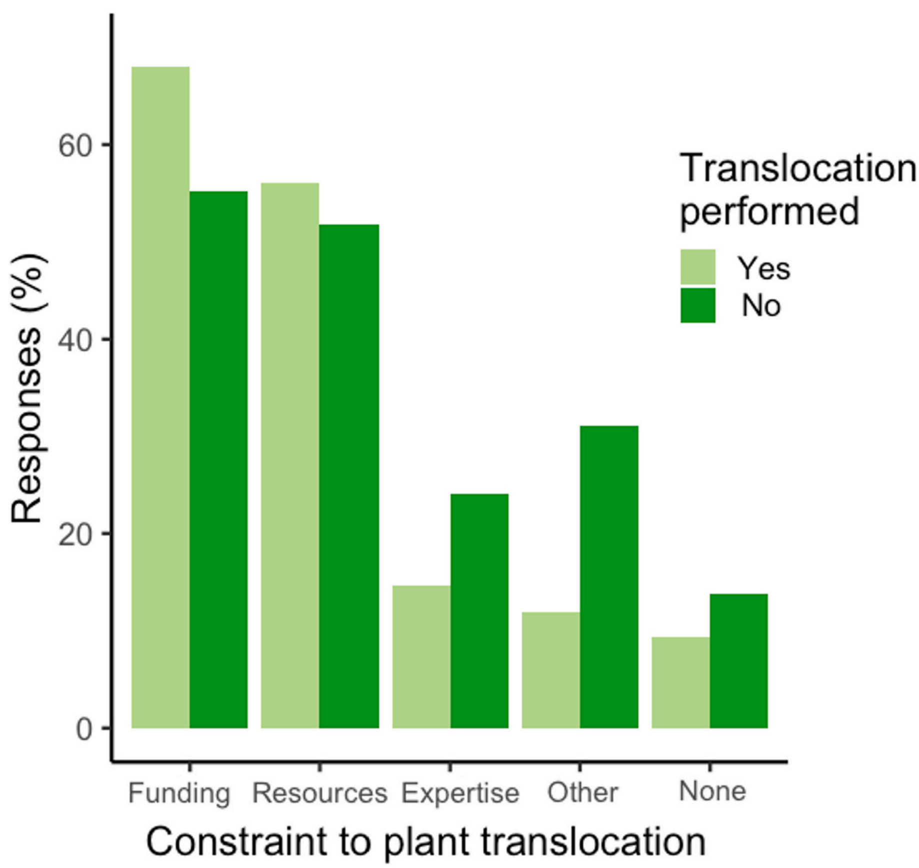

Fig. 3. Constraints to seed banks for plant translocation. Seed banks that have already performed plant translocation are indicated by light green, those that have not previously carried out translocation are in dark green. Multiple responses were allowed so the total percentage is over 100 %. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

indicated that they wished to carry out translocations using their collections in the future and would be willing to donate seeds for plant translocation to other organisations such as conservation bodies. Seed banks that had already performed plant translocation were more likely to respond positively to this question than those that had not (Fig. 4, Table S7).

3.2. *Literature review*

After duplicates were removed, the initial Web of Science and Scopus searches identified 250 publications. Most of the translocations mentioned in the literature used freshly harvested seeds or plants produced from fresh seeds. The seed source was unclear in four publications. There were 12 publications that described the use of seed bank

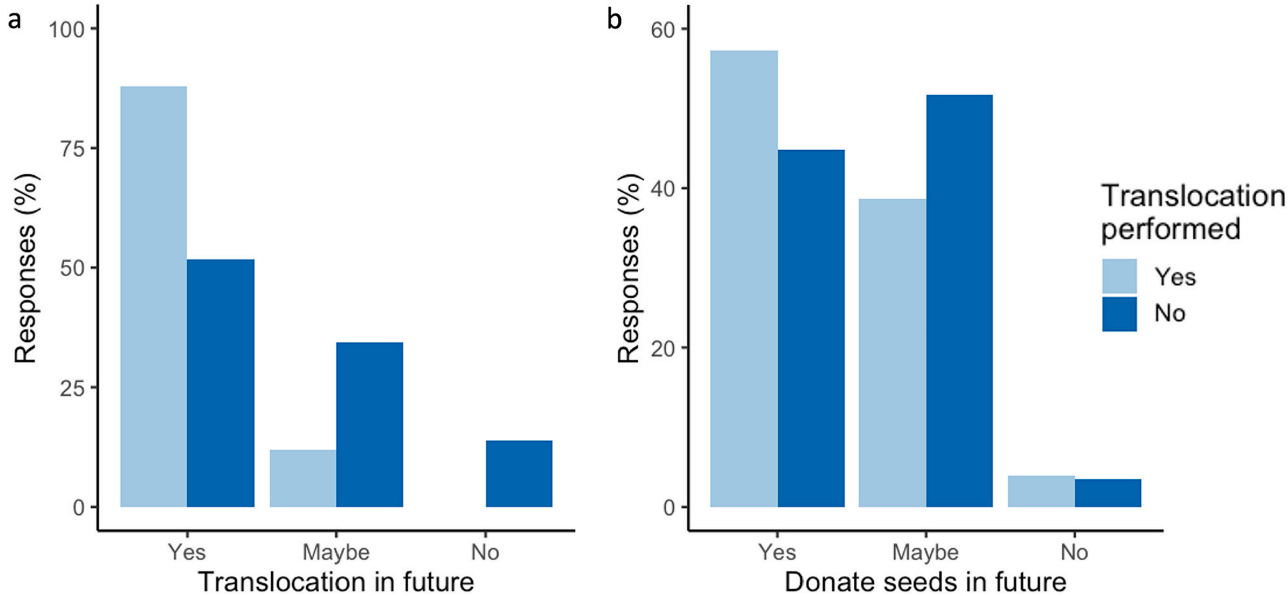

Fig. 4. Future plant translocation aspirations. a – Percentage of the responses indicating whether seed banks would like to perform plant translocation using their collections in the future; b – percentage of the responses indicating seed banks that would be willing to donate their seeds to other organisations for future plant translocations. Seed banks that have already performed plant translocation are indicated by light blue, those that have not previously carried out translocation are in dark blue. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

stored seeds in plant translocation. Three of the publications were review articles: Monks et al. (2019) provided an overview of the conservation of threatened species in Southwestern Australia including plant translocations from stored seeds of 32 populations of pathogen susceptible flora and three populations of *Banksia brownii*; Abeli et al. (2020) reviewed the potential of ex situ collections for extinct in the wild species recovery, with two examples of successful plant translocation using seed bank stored seeds for *Diplotaxis siettiana* and *Erica verticillata*; and a review of ex situ conservation for threatened species by Cochrane et al. (2007) mentioned the use of banked seeds for the successful reintroduction of 20 species. Two publications provided overviews of the conservation actions of specific seed banks: Chapman et al. (2019) reviewed the role of the MSB in protecting plant diversity in the UK providing examples of plant reintroductions from seeds held in long term storage, including the previously extinct in the wild *Bromus interruptus*; and a publication concerning conservation in the Majella National Park, Italy mentioned eight accessions of stored seeds were used in plant translocation (Cecco et al., 2020). Two articles were related to a project which aims to improve the conservation status of threatened endemics on six Mediterranean islands and has carried out 51 plant translocations, an unspecified number of which used seed bank stored seeds (Fenu et al., 2019, 2020). A further three publications investigated genetic differences between wild and translocated plants produced from stored seeds: Vanden Broeck et al. (2021) studied gene flow between exotic and native translocated *Populus nigra* in the Netherlands, with 60 % of the reintroduced trees produced from seed bank stored seeds; Gargiulo et al. (2019) compared wild and translocated *Pulsatilla vulgaris* across 15 different populations in England; and Monks et al. (2021) compared seven wild populations and three translocated populations of *Lambertia orbifolia* translocated across multiple years in Australia. Finally, two articles focused on the best methods for successful plant translocation: Albrecht and Long (2019) looked at the importance of habitat, herbivory and restoration techniques for successful plant reintroduction of *Astragalus* using seeds stored at the Missouri Botanical Garden, USA; and Reiter and Menz (2022) investigated the effect of microsite on translocation outcome of the rare orchid *Caladenia colorata* in Australia using seed bank stored seeds collected specifically for translocation.

4. Discussion

Our study is the first global one that has specifically investigated the use of seed bank stored seeds for plant translocation. From our questionnaire we found that seed banks do contribute towards plant translocation activities, with 88 % indicating that they would like to continue, thereby implementing Target 8 of the GSPC to make 20 % of ex situ collections available for restoration. However, the responses received were skewed towards the Northern Hemisphere, with most (82 %) from Europe and North America. Consequently, the results may not be a true global representation of how seed banks use their collections, with those in Asia and the Southern Hemisphere underrepresented. Nonetheless, there is an inherent bias in the location of seed banks, with over 90 % of ex situ collections held in Europe and North America due to historical and socioeconomic reasons (Mounce et al., 2017). The questionnaire responses may also reflect alternative approaches to plant conservation in different regions, where plant translocation activities are conducted by different agencies. For example, in Australia where there is a large number of threatened native species and frequent bushfires, there is an urgent need for species recovery and habitat restoration throughout the continent (Murphy and van Leeuwen, 2021). Whilst there have been many conservation translocations carried out in Australia, the majority have been performed by government agencies (Silcock et al., 2019). The role of wild species seed banks here, therefore, would be different compared to countries where seed banks play a more central role in translocations.

The proportion of seed banks that had carried out plant translocations using their collections was unexpectedly high at 72 %. Although it was emphasised within the given instructions that we would like responses regardless of translocations performed, respondents were possibly more inclined to complete the questionnaire if translocations had already taken place. A similar pattern was observed in a questionnaire on animal translocation where responses were more likely if the translocation had been successful (Reading et al., 1997). This bias towards higher engagement when there are positive outcomes also extends to publications, as studies relating to translocations tend to be favoured towards reporting successes rather than failures (Godefroid et al., 2011). Therefore, the true picture of translocation activities and their outcomes are currently limited and skewed. Although the proportion of respondents that had performed translocations was high, it could be inflated by translocations where material was specifically collected for that purpose and stored in a seed bank as part of a specified project. This differs from using seeds collected many years before for an undefined purpose, which could be rarer. Targeted material for use is reflected in the questionnaire responses, with 68 % of seed banks that had already performed translocation indicating that a primary purpose of the seed bank was short-term conservation for use, compared to only 24 % of seed banks that had not previously done translocation. Additionally, most translocations used seeds that were less than five years old, reflecting the short-term nature of the seed bank storage. Although most questionnaire respondents had performed plant translocations using their collections, the number of translocations per seed bank was relatively small (median of 12). However, the median number of translocations per seed bank in North America and Australia was 2.5 times the global value, suggesting there are regional variations in the priorities of seed banks for plant translocation.

Almost 90 % of seed banks that responded to our questionnaire indicated they had some form of constraint on plant translocation, with lack of funding and resources identified as the main limitations. Seed banks that had already utilised their collections for plant translocation were more likely to want to carry out or donate seeds for future translocations, suggesting there is a willingness to continue contributing to plant translocation activities. To address the funding and resource limitations, seed banks will have to find novel solutions. Many of the seed banks that responded to our questionnaire are publicly funded. With increasing limits on public money, these institutions will have to look for alternative funding sources, for example from the private sector, charities, national lotteries, and/or crowd funding. In addition, 38 % of respondents said they apply for funding only once in five years or never, suggesting there is scope for seed banks to be more proactive in searching for other opportunities. One innovative example is from the MSB where the public can “adopt a seed” or “save a species”, with the money going towards species conservation (Millennium Seed Bank, 2022b). Another example is a plant sponsorship programme organised by the Center for Plant Conservation, a network of ex situ collections in the United States and Canada which focusses on saving rare species from extinction (CPC, 2022). Too few seeds or a small collection size was also mentioned by seed banks as a constraint and can significantly limit the willingness of seed banks to use their collections for plant translocation. Having large numbers of propagules is cited as one of the key factors for establishing viable populations and thereby a successful outcome for plant translocation (Godefroid et al., 2011; Silcock et al., 2019). However, for many threatened species, their rarity and potential difficulty in setting seeds means that only a small number of seeds are available for collection without harming an already vulnerable wild population (Liu et al., 2020). To manage the limited collection size, seed banks may choose to restrict the number of seeds they make available to other organisations. For example, the MSB typically provides a maximum of 60 seeds per accession requested (Breman et al., 2021) which can put constraints on their use in large scale plant translocation activities and will likely not represent the full genetic diversity of a population. When larger seed numbers are requested, particularly from organisations that donate seeds, care needs to be taken that such requests do not deplete an already restricted resource. ENSCONET guidelines recommend that seed banks keep a base collection that is not distributed to other seed banks to ensure an appropriate number of seeds are maintained (ENSCONET, 2009). A basic understanding of phenology, population genetics and localities of multiple populations of target species remains key to ensuring sufficient numbers of seeds can be collected. Similarly, for many species, making small collections over different years could be required to increase seed numbers.

As well as the constraints faced by seed banks, several respondents highlighted that plant translocation is a last resort and is not in the conservation priorities of their seed bank. This is a valid concern given that plant translocations are considered risky and expensive, particularly at the setup stage (Zimmer et al., 2019) and have been found to have limited success (Godefroid et al., 2011; Drayton and Primack, 2012). It is important that translocations are fully justified with the risks and benefits thoroughly assessed, in accordance with the IUCN Guidelines for Reintroductions and Other Conservation Translocations (IUCN, 2013). However, although plant translocation is deemed precarious, delaying could lead to an even worse outcome for threatened species. With a rapidly changing climate, species' niches may be altered more quickly than expected (Antão et al., 2022) and consequently, plants produced from stored seeds may no longer be suitable for translocation back to the seed collection site (White et al., 2022). As a result, practitioners may be required to consider translocation outside of species ranges, increasing the potential for failure (IUCN, 2013). These risks could explain why there have been relatively few plant translocations carried out by individual seed banks. A potential solution would be to have seed banks specifically focused on restoration to carry out translocation activities (Merritt and Dixon, 2011). This approach may be suitable for areas that require extensive restoration but it requires a large amount of long-term investment and support from multiple agencies (Turner et al., 2016). Although not suitable for all types of translocation actions, the principal ideas of encouraging multidisciplinary collaboration and community involvement are key and could be incorporated into the practices of existing seed banks whose focus is on conserving wild species.

Knowledge exchange can help mitigate the risks related to undertaking translocation activities. However, the results from our literature review identified only 12 publications that mentioned plant translocation from stored seeds. Often the translocation was mentioned as part of a wider review of conservation actions, or the article was investigating differences between introduced and natural individuals, with the translocation outcome not the main focus of the paper. We also found that 66 % of questionnaire respondents did not have data on translocation outcome readily available, suggesting that the outcomes of translocation activities are often unpublished or even unrecorded. Undocumented outcomes have been found previously by Silcock et al. (2019) in Australia, where only 11 % of plant translocations had been reported in peer reviewed literature. The lack of published data may be partly because plant translocations are usually funded by government agencies, charities and/or NGOs as part of practical conservation programmes. Often these projects do not address a specific research question and are therefore not deemed suitable for scientific publication. Additionally, seed banks not attached to universities may lack the incentive to publish in the scientific literature. Results of plant translocations are therefore more often reported in technical documents, for example by the IUCN Species Survival Commission as case studies (e.g. Soorae, 2018, 2021), or in project reports inaccessible to the public. Grey literature such as these are difficult to search and, in many cases, not available online, hence it was omitted from our review. However, we recognise the importance of such material and encourage it to be more publicly accessible, for example through uploading to Open Access Repositories. International and national cooperation and sharing of information is key for seed banks to reach their full potential for plant conservation. Indeed, collaborations are often vital in order to achieve outcomes that would not be possible alone. This can be aided by sharing skills, knowledge, and expertise in plant translocation, thereby improving efficiency, and increasing the impact and profile of successful projects (Pearce et al., 2020). Collaborations will be even more important in the future for seed banks to achieve the conservation targets set beyond the current version of the GSPC.

To expand on the results of this perspective article, we make a number of suggestions for future study. Many of the regions not fully represented in the responses to our questionnaire have large areas of tropical and sub-tropical environments, where plant species tend to produce recalcitrant seeds (Wyse and Dickie, 2017). For these species alternative ex situ storage is required, either preserved as whole plants in botanic gardens (Irwin, 2022) or using in vitro and cryopreservation methods (Walters and Pence, 2021). Future research should explore the use of collections in these alternative storage conditions in plant translocation to help enhance our overall understanding of wild species conservation, particularly in underrepresented areas. Translating questionnaires into local languages may furthermore increase global participation. Future work could also explore the extent to which agricultural gene banks and other governmental agencies contribute towards wild species conservation. Some nations may already utilise existing capacity for translocation activities, such as through broadening the remit of their agricultural gene banks to work on wild species (e.g. crop wild relatives). The more information we have on the current role of ex situ collections in plant translocation, the better we can optimise their use for wild species conservation.

5. Conclusions

The results of our study show that seed banks are active in plant translocation, but more can be done to fully exploit this valuable resource. It is increasingly important for seed banks to raise funds, form connections, and engage the public on their value for conservation. Networks are especially important for sharing knowledge between practitioners, particularly as plant translocations using banked seeds are rarely published in the scientific literature. Seed banks are already contributing to vital work in plant conservation and there is willingness to do more, suggesting seed banks will have to be more innovative and proactive in finding new funding opportunities. Now, more than ever, seed banks should work to achieve their full potential in helping to halt the rapid biodiversity loss we are experiencing around the world.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

F.J. White: Conceptualization, Methodology, Formal analysis, Writing – original draft, Visualization. **A. Ensslin:** Conceptualization, Methodology, Writing – review & editing. **S. Godefroid:** Conceptualization, Methodology, Writing – review & editing. **A. Faruk:** Methodology, Writing – review & editing. **T. Abeli:** Methodology, Writing – review & editing. **G. Rossi:** Writing – review & editing. **A. Mondoni:** Conceptualization, Methodology, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

We are very grateful to everyone who completed the questionnaire and to the networks and individuals who helped with distribution and promotion. The dissemination of the questionnaire was enhanced by the networking activities organised by the EU COST Action CA18201 — An integrated approach to conservation of threatened plants for the 21st Century (ConservePlants), supported by COST (European Cooperation in Science and Technology). Thank you to four anonymous reviewers whose comments helped improve the manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2023.109991.

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