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RESEARCH ARTICLE

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# Status and future of seed conservation of threatened plants in the post-2020 era

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†This paper is dedicated to the memory of our colleague and friend Dr. Sara Magrini, director of the Tuscia Germplasm Bank and former president of the RIBES network of Italian seed banks.

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**Societal Impact Statement**

Ambitious targets have been set to backup seeds of threatened plants by the global strategy for plant conservation (GSPC), but it is unclear in how far these targets have been met and how seed collection should be organized to meet future challenges. Here, we provide an overview of the status of 44 countries in achieving seed conservation targets. We show that progress varies strongly across countries, but in general, targets of the 2011–2020 GSCP have not been reached. By a regional example, we illustrate how seed collection could be organized to safeguard our threatened flora.

**Summary**

- Seed banking of wild plants is a central pillar of conservation strategies for threatened plants. Target 8 of the Global Strategy for Plant Conservation (GSPC) called for at least 75% of threatened plant species to be conserved ex situ by 2020, but to what extent countries have achieved this target is unclear. Consequently, it is unknown how seed banking should be organized in future to safeguard plant diversity and support the increasing demand for seeds for habitat restoration.
- We conducted a comprehensive survey across 44 countries in Europe and western Asia and collected information on seed bank stocks of native taxa. We harmonized the taxonomic names across the collections and matched them against a database of national plant Red Lists to assign each taxon its IUCN (International Union for Conservation of Nature) threat status in its country of origin. We analysed each country's achievement in terms of the conservation of its threatened flora and evaluated the quality of the collections in terms of genetic representativeness and seed quantity.
- We found that none of the studied countries had reached Target 8 of the GSPC by 2020. While a few countries had come close to it, on average only 21% of threatened taxa were conserved across countries.

- Our results demonstrate that the current seed conservation strategy has not met conservation demands. Using an example from Belgium, where considerable progress has been achieved by investing in a network of volunteer seed collectors, we show how future seed collection could be organized in collaborative community-based approaches.

**KEYWORDS**

ex situ conservation, GSPC Target 8, red list status, seed banking, threatened plants, volunteer network

## 1 | INTRODUCTION

Conventional seed banking has become one of the most important strategies to preserve plant diversity for human health, food security and biodiversity conservation (Colville & Pritchard, 2019; Harrison et al., 2020; Hay & Probert, 2013; O'Donnell & Sharrock, 2017). Current estimates suggest that there exist around 1750 seed banks and genebanks worldwide, storing approximately 50–60,000 wild taxa (O'Donnell & Sharrock, 2017; Walters & Pence, 2021). The need for safeguarding the genetic diversity of wild plants has been acknowledged in international treaties such as the Convention on Biological Diversity (CBD) as well as the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA; FAO, 2014). This commitment was further reflected in the CBD's Global Strategy for Plant Conservation (GSPC), where Target 8 ambitiously aimed to secure at least 75% of all threatened plant species in ex situ collections by 2020 (SCBD, 2010). Moreover, at least 20% of the seeds should be available (ready-to-use) for translocation and restoration. Native seed use, especially for habitat restoration, has greatly increased in recent years (Goodale et al., 2023; Merritt & Dixon, 2011). This purpose has since been carried forward in Target 4 of the new GSPC for the period 2020–2030, which is associated with the Kunming-Montreal Global Biodiversity Framework (https://www.bgci.org/news-events/published-today-new-gspc-summary-document/).

Conventional seed banking is effective for storing desiccation-tolerant seeds (generally called "orthodox" seeds) at around 5% water content, typically under 15% relative humidity (RH) and at −18°C, or at nonfreezing temperatures (i.e., 1–10°C) if freezing is technically not possible or poses challenges (FAO, 2014). Under these conditions, seed aging is slowed down considerably because metabolic activity is reduced at very low temperatures and ice crystal formation is prevented by prior drying. As a consequence, the lifespan of seeds can be extended many times over (Nadarajan et al., 2023). However, not all species can be conserved under these conditions, for instance, those producing recalcitrant seeds (i.e., non-desiccation-tolerant), or reproducing only vegetatively. For those species, other techniques such as cryo-preservation (storage of the excised embryo or regenerative tissue in liquid nitrogen) must be employed (Walters & Pence, 2021).

Ex situ conservation of threatened wild plants is mostly carried out by seed banks, often affiliated with universities or botanic gardens, while others are financed by municipalities or foundations (O'Donnell & Sharrock, 2017). Several studies on seed collections with regards to the GSPC targets have been published recently, providing some insights into conservation efforts made at the institutional, national (e.g., Liu et al., 2018; Teixido et al., 2017) and international levels (Godefroid et al., 2011; O'Donnell & Sharrock, 2017; Rivière & Müller, 2018). Their findings are consistent with the general overview given in the report of the CBD on the achievements of the GSPC targets by 2020, stating that progress has been made, but most targets, including Target 8, have not been fully achieved (Sharrock, 2020). There are, however, some difficulties with these conclusions. Firstly, while it appears that most countries might not have achieved the GSPC targets, precise information on the extent of progress is lacking. This hinders a deeper evaluation and understanding of what has been accomplished and whether the current collection strategies should be revised. Secondly, the absence of a common reference scale for threatened species across studies, that is, whether targets are evaluated at the national, regional or continental level, limits their comparability. Since the GSPC does not specify the reference scale for red listing, continent-wide studies such as Rivière and Müller (2018) have used the European Red List (Biltz et al., 2011) as a reference whereas single country studies have referred to their national red lists (Kyratzis et al., 2024; Liu et al., 2018, 2020; Teixido et al., 2017). This difference in reference lists strongly influences the proportion of taxa secured. For instance, while the European Red List for vascular plants presents 467 taxa threatened across the whole of Europe, Switzerland alone has more than 700 taxa listed as threatened (Bornand et al., 2016). While taxa threatened on the global or continental level should undoubtedly be given the highest priority, as they face the highest extinction risks, many taxa have not been assessed on these levels (Sharrock, 2020). Moreover, because most conservation planning is carried out at the national level, only country-level analysis can adequately inform conservation planners on collection gaps within individual countries.

Another difficulty in ex situ conservation is the lack of a comprehensive database on seed stocks of wild plant species (Godefroid et al., 2011). In Europe, for instance, the European Native Seed Conservation network (ENSCONET), founded in 2005, currently lists 45 members from 20 countries, and this is only a subset of all the institutions involved in wild plant seed banking (O'Donnell &

Sharrock, 2017). Even within countries, centralized databases on seed stocks are rare. It is therefore not known precisely where each country stands concerning Target 8 of the GSPC, making it difficult to evaluate national conservation needs and to effectively plan future ex situ conservation strategies.

Ex situ collections such as seed collections in seed banks are intended to conserve the genetic diversity of the species as found in its natural habitat (BGCI, 2012; Hoban, 2019). To achieve this without resorting to costly genetic studies, indicators have been developed to ensure genetic representativeness of collections of wild species. The ENSCONET seed collection guidelines defined the number of seed accessions per taxa (≥5) as a realistic indicator (in the absence of better advice for a particular taxon) to achieve a good genetic representation of taxa (ENSCONET, 2009a). Moreover, to respond to Target 8b of the GSPC, that is, to make 20% of all seed collections available for in situ activities such as reintroductions and reinforcements, ENSCONET has set the threshold of 5000 seeds per accession to account for seed loss through mortality, viability testing and the use for in situ conservation or research. Taken together, these two measures (accession number and seed number) provide a valuable indicator of the ability of a seed collection to fulfil its main aims of genetic representation and usability (henceforth referred to as 'quality of collections'). A last indicator for usability is the viability of a seed accession, which should not fall below 75% of its initial value (ENSCONET, 2009b). However, the few studies that have analysed these indicators suggest that they are often not met (Ferrando-Pardo et al., 2016; Liu et al., 2018).

In this study, we took advantage of the extensive COST-Action network of plant conservation institutions to conduct a comprehensive survey on seed conservation of wild plant taxa across 44 countries in Europe and western Asia. Our primary objectives were to determine (1) how many wild native plant taxa (including subspecies) are stored across the seed bank network, (2) the status of individual countries as of 2020 with regards to Target 8 of the GSPC and (3) the quality of the collections as measured by the number of accessions per taxon and the number of seeds per accession. By doing so, we provide a detailed assessment of how countries have progressed towards Target 8 of the GSPC, considering not only the Red List status of banked taxa but also their genetic representativeness and accessibility.

As an additional objective, we sought to outline a road map for achieving significant ex situ conservation of threatened taxa at the national or regional level. For this, we estimated the average time required for participating countries to achieve Target 8 based on current progress. We highlight the example of the Flanders region in Belgium, where strategic investment in a seed collector network has allowed the region to boost the percentage of threatened taxa stored in their seed bank from below 50 to over 75% within just 4 years. We discuss how this approach could provide a model for organizing and streamlining seed collections of threatened plant taxa across countries.

## 2 | MATERIALS AND METHODS

### 2.1 | Seed banks identification and survey

The survey was conducted as a part of COST Action CA18201 'ConservePlants' (Fišer et al., 2021). In 2020, with the help of the country representatives from the Action network, around 200 potential seed banks were identified. Each institution was contacted to verify its role as a seed bank by enquiring about the purpose and conditions of seed storage. Only institutions that store native wild-collected seeds for conservation purposes and follow specific procedures for drying and storing in a cool environment (5°C or lower) were retained in the list. Existing seed bank networks such as the ENSCONET consortium (http://ensconet.maich.gr) and EURISCO, the European Search Catalogue for Plant Genetic Resources in crop genebanks (https://eurisco.ipk-gatersleben.de) were also contacted to get contact details of their members or information on their collections. Crop genebanks were asked whether they held seed stocks of wild taxa, such as crop wild relatives. Seed stocks of crops or landraces were not considered. Our study therefore focused on conventionally banked seeds and did not consider other ex situ seed conservation techniques such as cryobanking or whole plant conservation (e.g., in vitro cultivation or living collections). In total, we contacted 311 institutions from 40 countries, of which approximately half did not respond, and around 15% of those who responded were not included because they did not meet the required criteria.

Information on seed bank collections was ultimately obtained from 106 seed banks across 29 countries (Figure 1, Table S1). Most participating countries were from Europe as it is defined politically by the United Nations (https://unstats.un.org/unsd/methodology/m49/). From the countries contacted outside Europe, Israel was the only one who responded. A survey was created using spreadsheets to collect information about seed bank collections. A proforma template was sent to all participants containing 30 fields with information on, among others, the taxonomic name of the stored taxon, storage method, date of seed harvesting and storage, origin of the seeds and number of seeds stored. The full survey questionary can be found in the Supporting Information (Tables S2 and S3).

### 2.2 | Data cleaning and harmonization of taxonomic names

The data were compiled, and taxonomic names were corrected for spelling or grammatical errors (such as incorrect species epithet endings, e.g., *vulgare* vs. *vulgaris* etc.). Duplicates of seed accessions (i.e., the safety backup of a particular seed collection event stored in another seed bank) were identified and removed to avoid double counting. Given the variability of taxonomic references used (both current and outdated) across seed banks when assigning scientific names to their collections, significant effort was made to harmonize taxonomic names and align them with current nomenclature. This

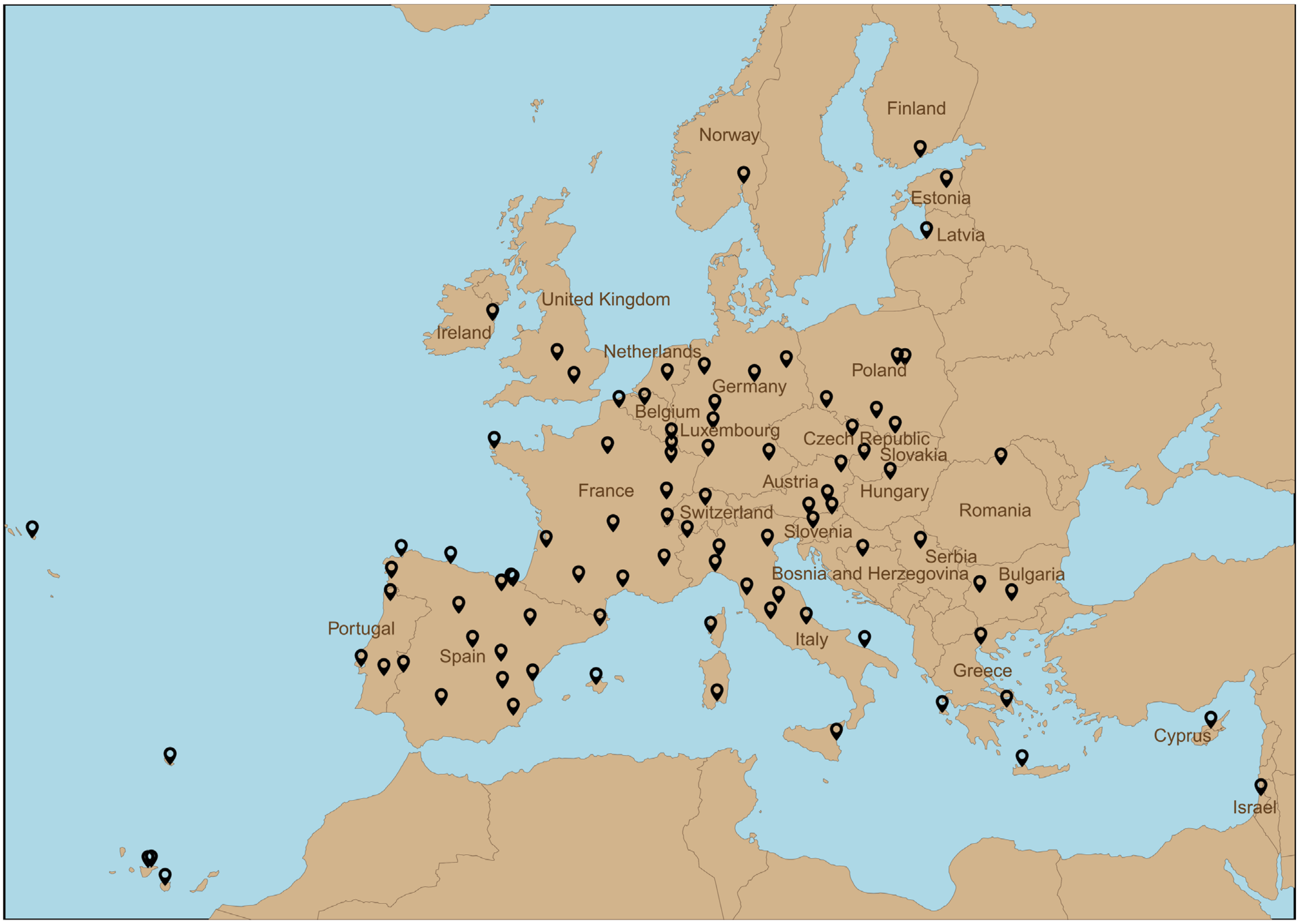


**FIGURE 1** Map showing the location of the seed banks participating in the COST (European Cooperation in Science and Technology) Action seed bank survey.

effort was crucial, as it allowed us to determine not only the number of taxa stored in each seed bank or country but also the number of taxa conserved across all participants or geographical scales. This was particularly important as the high number of synonyms (i.e., taxa listed under different names but representing the same taxonomic entity) could have otherwise significantly inflated such estimates. Scientific names were harmonized by matching them against the World Checklist of Vascular Plants (WCVP), which serves as the taxonomic name backbone for Plants of the World Online portal (POWO: https://powo.science.kew.org/). Because taxonomic names were mostly provided without author names, we employed the method described in Lončarević et al. (2024) to assign accepted taxonomic names during the name matching process. With this approach, we assigned accepted names to about 80% of accessions. If a taxonomic name was not found in POWO, we used additional resources to confirm its validity, taxonomic status and accepted name. These resources included: the World Flora Online (WFO, https://www.worldfloraonline.org/), the International Plant Names Index (IPNI, https://www.ipni.org/), the Euro+Med PlantBase (https://europlusmed.org/), Global Biodiversity Information Facility (GBIF, https://www.gbif.org/) and Tropicos (https://www.tropicos.org/home). However, as these resources need some time to include newly described names or taxonomies, we also searched in recent literature and in locally published databases and floras. If a clear and reliable record of the publication of the name was found, it was considered valid. For instance, we considered names if they were found in the Norwegian Biodiversity Database (https://biodiversity.no/) and the Canarian Biodiversity Databank (https://www.biodiversidadcanarias.es/biota/normas?lang=en), both of which serve as national references for plant conservation. In very difficult cases, the seed banks were contacted and asked to provide the reference for the name used. With this procedure, we were confident that we identified a maximum number of names, including those that are scientifically published taxa, but not yet recognized by the main international taxonomic databases. After the red list status attribution (see below), autonyms were assigned to the species level to avoid double counting, while accepted subspecies were retained. With this procedure, we were able to assign an accepted name to over 99% of the taxa (where a complete name was given) of our database. As our aim was to analyse the banked seeds of the native flora, we excluded ornamental, established exotic or invasive taxa. We also excluded a few collections originating from countries geographically distant from the country in which the seed bank was located (e.g., from another continent such as South America), as these collections were isolated events without a clear conservation purpose.

## 2.3 | Red list statuses and other threatened taxa lists

We considered taxa as threatened when they had one of the following IUCN red list statuses: CR, EN and VU (CR = critically endangered, EN = endangered and VU = vulnerable as defined by the IUCN) (see Mace et al., 2008), henceforth called red-listed taxa for simplicity. Although we requested the national red list (RL) status of each taxon in the collections, only some seed banks provided this information. Therefore, we took advantage of the development of a database of national red lists of all European and some additional countries (RL database; Lončarević et al., 2024). We matched taxon names in the RL database against our own database to assign a national RL status for each accession, based on the country from which seeds were harvested. As a result, accessions of the same taxon stored in the same seed bank could have different RL statuses if seeds were harvested in different countries. Only 36% of the taxa in our database could be matched to a country-specific national RL status. However, as most national red lists do not list taxa considered not threatened (LC), most of the nonmatched cases were likely nonthreatened or, to a much lesser degree, taxa which have not yet been evaluated in certain countries.

For an additional, more focused analysis on the European continent, we matched our database against the list of 1842 Europe-wide threatened plants of Holz et al. (2022), by selecting only taxa that are threatened with extinction across their whole range in their database. Moreover, we matched our database against the list of 706 priority species for reaching Target 8 for European seed banks, established by Rivière et al. (2018). The aim was to quantify the progress since the ENSCONET publication concerning the conservation of Europe-wide priority species. The nomenclature used by Holz et al. (2022) and Rivière et al. (2018) was not harmonized as that by Lončarević et al. (2024). This limitation may lead to an underestimation of seed bank representation due to nonalignment of synonyms or changes in taxonomy. However, Holz et al. (2022) used the WCVP as a taxonomic name backbone and Rivière et al. (2018) checked the taxonomic names against the Euro+Med database and The Plant List (precursor of the WFO). We hence consider any underestimation of taxa represented in seed banks to be minimal and unlikely to affect our main conclusions and recommendations.

## 2.4 | Achievement of GSPC Target 8 and quality of collections

For each country, the number of taxa as well as the number of red-listed taxa stored in seed banks was assessed. We then calculated the ratio of red-listed taxa conserved in seed banks based on the total number of red-listed taxa per country (Lončarević et al., 2024). Moreover, the compiled seed bank database was compared against the lists of Rivière et al. (2018) and Holz et al. (2022) to obtain a more focused understanding of how many Europe-wide threatened taxa were secured and how much progress had been made for Target 8 priority taxa.

To assess the quality of the collections, we examined genetic representativeness with respect to the number of accessions stored per taxon in combination with the quantity of seeds per accession, to ensure the availability of seeds for conservation and research (ENSCONET, 2009a; see introduction). Due to the paucity of information, we could neither consider the number of mother plants from which seeds were collected nor the viability or germination rate of the conserved seed lots. We categorized the taxa into 'high representation' when five or more accessions per taxon were conserved and 'low representation' when fewer than five accessions were conserved, as recommended by ENSCONET (2009a). We acknowledge that this is a rather crude approach, as it does not consider the distribution of these accessions across the taxon's distribution range or number of seeds per accession. However, it provides a general indication of the proportion of taxa, which are likely genetically underrepresented (see also Carta et al., 2025, who adopted the same approach).

To indicate the availability of seeds for conservation measures (GSPC Target 8b), we assessed the number of seed lots with more than 5000 seeds as a benchmark for a quality seed lot suitable for long-term conservation and utilization (ENSCONET, 2009a). For approximately 58% of the accessions (87,107 out of 150,936), seed counts could not be used in the analyses due to missing data or because only seed weight was reported, which could not be converted into seed numbers without additional information (e.g., 1000 seed weight).

## 2.5 | Post 2020: How To Move Forward

### 2.5.1 | Perspectives for Target 8

To project future achievement of the GSPC targets, all contributing seed banks were asked to estimate the average number of new threatened taxa they obtain each year, selecting from the following range classes: 1 = 1–20, 2 = 21–50, 3 = 51–100, 4 = 101–200 and 5 = >201 new RL-taxa. Based on the responses, an average increase of new red-listed taxa relative to the still missing RL-taxa per country was used to estimate the average number of years required to achieve Target 8 of the GSPC. These estimates assumed consistent annual collection rates and no overlap in taxa collected by different institutions within the same country. Also, only countries with a seed bank participating in our survey were considered. Although our calculations may be rather optimistic, our aim was to gain a general understanding of the minimum time span required to achieve Target 8 under a 'business as usual' strategy. Of the 106 institutions surveyed, 56 provided information on the average annual collection of new RL-taxa. From this information, we calculated a mean of new RL-taxa per country. The midpoint of range classes was used to calculate an average number of new RL-taxa per country (1 = 10.5, 2 = 35.5, 3 = 75.5, 4 = 150.5; no class 5 was reported). For institutions that did not respond, we assumed they would still collect some new taxa and assigned to them the average value of new RL-taxa across all respondents (2.3 = range class 1). The number of years required to reach Target 8 for each country was then calculated by dividing the number of taxa still missing to achieve Target 8 (75% of the number of total RL-taxa minus the number of taxa already stored) by the number of new RL-taxa per year.

### 2.5.2 | The example from Belgium

In Belgium, seed collection of the country's threatened flora began in 1989 at Meise Botanic Garden, with the establishment of the only seed bank in the country meeting FAO standards (i.e., drying the seeds at 15% relative humidity and storing them at cold temperatures) (maximum 5–10°C, FAO, 2014). After three decades of seed collecting by the botanic garden staff, the country was still far from reaching GSPC Target 8, with only 33% red-listed taxa—combined across both regional lists—being safeguarded in the seed bank, and 49% specifically for the Flanders region. In 2020, Meise Botanic Garden revised its seed collection strategy and teamed up with a local nature conservation NGO, with which they had been collaborating for years for in situ conservation projects. The NGO hired a regional coordinator, who was trained in seed collecting by the seed bank staff, and who coordinated and accompanied around 60 volunteer seed collectors recruited from the NGO's volunteer network, to collect seeds from rare and endangered species in the Flemish part of Belgium. The programme was financed by the authorities of the Flanders region, and a species priority list was developed by the seed bank team with priorities being between one and four. A remuneration according to priority was paid by the Meise Botanic Garden to the collaborating NGO for each validated seed lot collected. We requested data on seed collections of red-listed species from Flanders before and after the implementation of the volunteer seed collector network. Moreover, information on the financial costs of the network and its organization and collaboration with the seed bank at Meise Botanic Garden was obtained.

## 3 | RESULTS

### 3.1 | General seed bank stocks

After data cleaning, the final dataset included 150,935 seed bank accession records from 106 seed banks across 29 countries (Figure S1, Table S1). After taxonomic harmonization, we identified 12,651 accepted taxa within the dataset. However, for 6831 accessions (2702 taxa), the country of origin of the seeds was not indicated, and these were therefore excluded from subsequent analyses.

Seed banks predominantly stored seeds harvested in their own country. Nonetheless, approximately one third of the seed banks also held seeds from at least one other country. Notably, the Millennium Seed Bank managed by Royal Botanic Gardens, Kew, UK, held seeds from 36 other European countries. Altogether, we assembled data on seed bank holdings from 44 countries (Table S1). Of these, 15 either lacked a national seed bank or, if they had one, did not participate in our survey (see Table S1).

The number of accessions and taxa stored varied considerably among countries, with Spain holding the maximum of 38,406 accessions and 4685 taxa. Remarkably, across all seed banks, 3320 taxa (26%) were represented by only a single accession, while the timber species *Pinus sylvestris* was, with 4763 accessions, the most represented.

### 3.2 | Achievement of Target 8 and quality of collections

The proportion of red-listed taxa among all taxa stored from a certain country varied strongly (Figure 2). In total numbers, the country with the highest number of red-listed taxa stored in seed banks was Spain

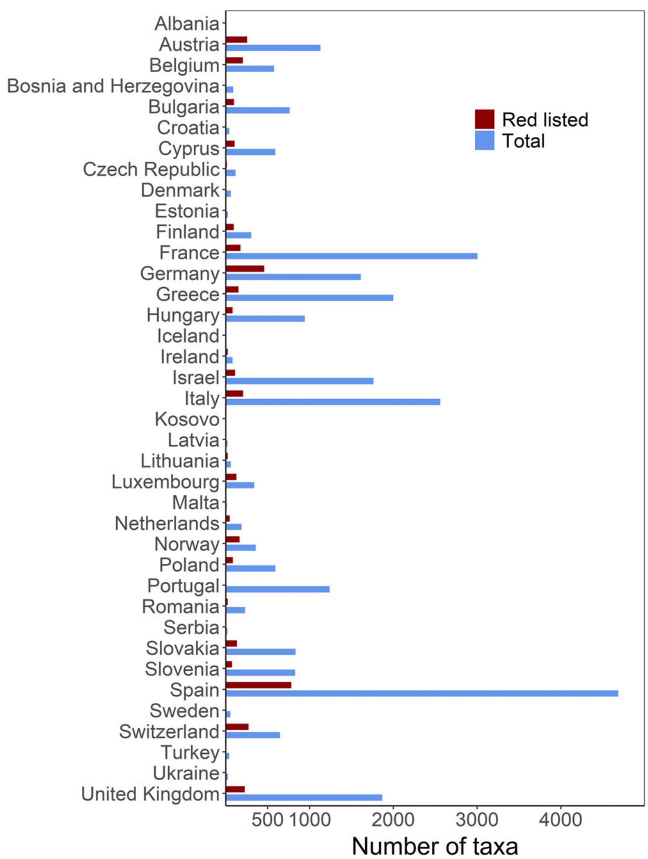


**FIGURE 2** Total number of taxa (blue bars) and number of red-listed taxa per country (according to each country's own Red List; red bars) stored in 38 countries by 2020. Note that the accessions may be stored in seed banks in the own country of origin but also in other countries if seeds have been sent or collected by seed banks from other countries.

with 781, followed by Germany with 460. However, when analysing the percentage that each country has secured of their red-listed taxa, the picture changed slightly with the United Kingdom and Israel at the top, both having 65% of their red-listed taxa stored (Figure 3). On average, only 21% of red-listed taxa were secured in seed banks across all countries. Of the 1842 Europe-wide threatened taxa listed by Holz et al. (2022), 1571 were successfully matched against the RL database from Lončarević et al. (2024) and 42% of these (660) were conserved. From the list of European priority species for Target 8 compiled by Rivière et al. (2018), 58% (432) were conserved in seed banks. There were 16 taxa held in seed banks, which are considered as regionally extinct in their respective countries of origin, and two taxa, *Bromus interruptus* (Hack.) Druce and *Lysimachia minoricensis* J.J.Rodr, which are considered as extinct in the wild.

About 44% of all taxa were represented by samples from more than five populations, in line with the recommendation from the ENSCONET (2009a) guidelines. However, this proportion decreased to 32% when considering only taxa that are red listed in their country of origin. On average, only 12% of taxa per country met the threshold of five accessions for conservation, with proportions ranging from 0 to over 50% (Table S1, Figure 4). Among accessions with reported seed counts, 44,229 accessions (70%) had fewer than 5000 seeds and one quarter (26%) even fewer than 500 seeds. For red-listed taxa, 75% of accessions did not reach the threshold of 5000 seeds and 36% were below 500.

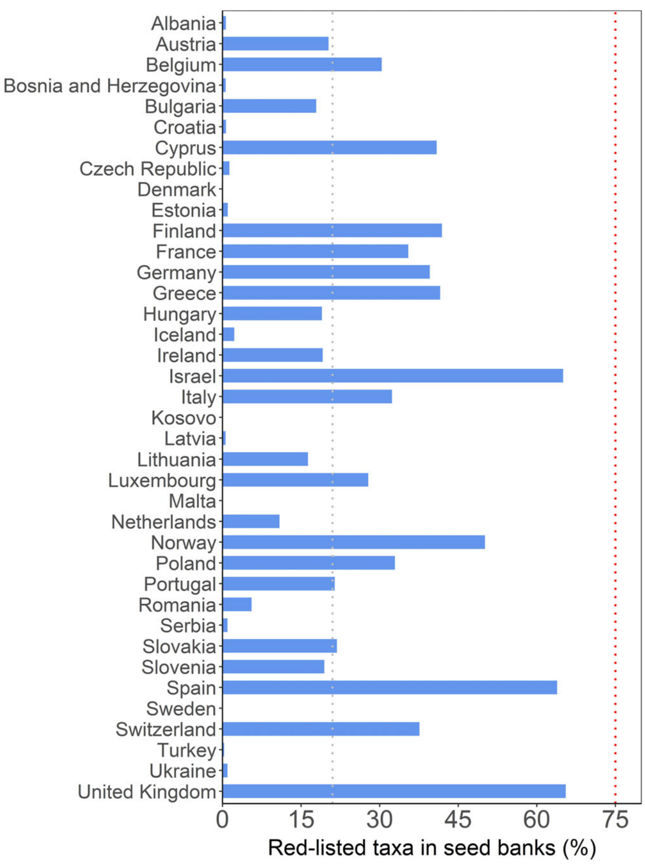


**FIGURE 3** Percentage of red-listed taxa (based on national Red Lists) secured in 38 countries by 2020. The red dashed line indicates the Target 8 of the Global Strategy for Plant Conservation (GSCP), which recommends having 75% of red-listed plant species conserved ex situ. The grey dashed line indicates the average of 21% covered across all countries.

## 3.3 | Post 2020: How To Move Forward

### 3.3.1 | Perspective for Target 8

Most seed banks reported collecting between 1 and 20 new red-listed taxa per year, although some collected more than 100 per year (Table S4). The estimated time to reach Target 8 ranged between less than 1 and up to 70 years (Table S1), with a mean across all countries of 18.3 years.

### 3.3.2 | The example from Belgium

Thanks to professional coordination and support for the network of around 60 volunteers, the Meise seed bank managed to collect and store a total of 1259 accessions of 512 taxa within 4 years—around

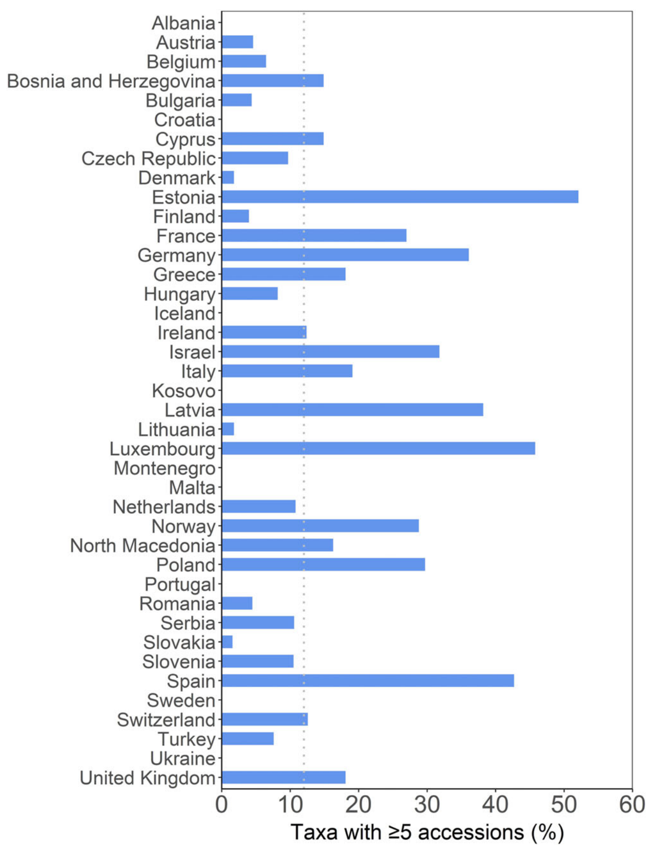


**FIGURE 4** Per country overview of the percentage of taxa being stored with 5 or more accessions across 106 seed banks. The grey dashed line indicates the average of 12% across all countries.

315 accessions per year. This boosted the percentage of red-listed taxa from 49% in 2020 to 76% in 2024 (Figure 5). The number of accessions increased even more strongly than the number of taxa, indicating that a considerable effort was also made to collect multiple origins per taxon.

## 4 | DISCUSSION

We studied the status of seed conservation of threatened wild plants in seed banks with regards to GSPC Target 8 across 4 countries. By harmonizing taxonomic names and comparing seed bank accessions with the national RL database (Lončarević et al., 2024), we evaluated the representation of wild and threatened plant taxa in ex situ collections as well as their quality in terms of genetic representation. Moreover, by estimating future conservation efforts and by presenting conservation strategies implemented in a specific region, we provide a perspective for future seed conservation to ensure an optimal preservation of our threatened flora.

### 4.1 | Achievement of GSPC Target 8

Our extensive dataset, comprising over 150,000 seed accessions across 106 institutions, shows that seed banking has become a major instrument in current efforts to safeguard native plant diversity and mitigate the loss of threatened taxa and their populations. However, number of accessions, taxa and percentage of the red-listed flora stored varied considerably across countries and, according to our results, none of the studied countries has achieved Target 8 of the GSPC. While this is congruent with the existing reviews on the progress towards the GSPC targets (e.g., Pain et al., 2020; Sharrock, 2020), our study is the first to provide detailed numbers on a country basis. Although several countries have come close to meeting Target 8, many others exhibit very low numbers or even a complete absence of stocks of wild plant taxa. Among the 4 countries from where seed accessions were conserved, 21 either had no national, red-listed taxa stored in seed banks (e.g., because they do not have a red list for their country) or stored less than 5% (Table S1). Countries with several wild seed conservation institutions were more likely to have progressed more, but even some countries with only a few seed banks (e.g., the United Kingdom, Belgium, Finland or Norway) have secured a considerable part of their threatened flora.

A recent survey using the same network of seed banks showed that limited funding was one of the main obstacles preventing seed banks from increasing species coverage (White et al., 2023). While it is encouraging that international policy has recognized the value and potential of ex situ conservation, such recognition will have limited impact if national or international financial support does not reflect this aspiration. However, the relatively low proportion of red-listed to total taxa stored (17% on average) also suggests that coverage may also be increased with a higher focus on threatened taxa. While the majority of species worldwide (in temperate climate zones and in the Mediterranean over 97%; Wyse et al., 2017) can be secured ex situ by conventional seed banking, plants that cannot be banked (called exceptional species) represent significant phylogenetic lineages (see Carta et al., 2025). Moreover, in tropical and subtropical forests, exceptional species can represent almost 20% of the flora (Wyse et al., 2017). For those taxa, complementary conservation approaches such as cryo-banking or living collections are needed (Walters & Pence, 2021).

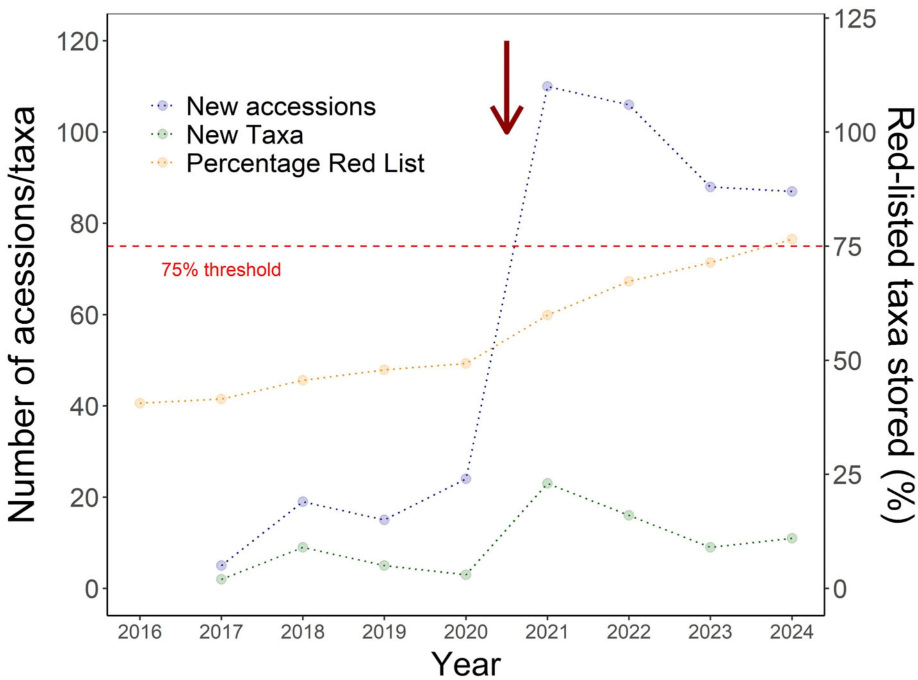


**FIGURE 5** Number of new accessions (blue dots), new taxa (green dots) and percentage of accumulated, red-listed taxa (yellow dots) per year of seeds from the Flanders region stored in the seed bank of Meise Botanic Garden from 2016 to 2024. The red dashed line indicates the Target 8 of the Global Strategy for Plant Conservation (GSCP) (SCBD, 2010) of having 75% of red-listed plant species conserved ex situ. The red arrow indicates the starting year of the collaboration of the seed bank with a coordinator and the volunteer seed collector network.

## 4.2 | A focus on Europe

As of 2020, European seed banks collectively conserved 11,751 taxa, approximately half of the native flora based on estimates of 20,000–22,000 taxa (Carta et al., 2025; Holz et al., 2022) and, on average, around a fifth of the red-listed flora in each country (Table S1). However, from 12 European countries (taking the official 50 European country definition from the United Nations: https://unstats.un.org/unsd/methodology/m49/), no seed stocks were reported in our survey. While southern European countries have in general a more diverse flora and also a higher number of red-listed plants (Myers et al., 2000), they have established national networks of seed banks (e.g., in Spain, Greece, Italy and France), allowing them to respond more effectively to this challenge. In general, seed conservation of wild plant species appears to be more developed in western and southern European countries such as Germany, France, Spain, Italy, but less so on the Balkan Peninsula (except for Greece) or some countries in northern Europe (e.g., the Baltic States, Denmark or Sweden). Only half of the European threatened taxa listed by Holz et al. (2022) were conserved in seed banks, and the proportion of priority taxa identified by Rivière et al. (2018) increased only moderately from ~50% in their 2017 analyses to 58% in our 2020 dataset. This shows that even with road maps and prioritization tools, seed banks in Europe have not been able to achieve internationally set conservation targets.

## 4.3 | Quality of seed collections

While the species coverage has been addressed in several studies on seed conservation of wild plants, only a few have also examined the genetic representativeness and seed number. In a regional study from the Valencia region, Ferrando-Pardo et al. (2016) found that less than 40% of the threatened species were stored as high quality seed collections with respect to genetic representation (number of populations) and germplasm quality (seed number and germination rate). Similarly, the analysis of the ENSCONET collections by Rivière et al. (2018) showed that more than half of the existing collections of threatened European plants did not meet quality standards, and a recent analysis of Mediterranean seedbanks confirmed a high number of single accession taxa (De Vitis et al., 2025). Concerning the usability of the collections, even in flagship institutions such as the Millennium Seed Bank in the United Kingdom, only one third of the accessions exceed the threshold of 5000 seeds per accession (Liu et al., 2018).

In our dataset, a mean of 3.6 accessions per taxon indicated a generally insufficient representation of genetic diversity within taxa. Higher values were found mostly for crop wild relatives in genebanks (e.g., timber species or forage plants), which are economically important but often lack conservation value. While at the European level, one third of red-listed taxa are preserved as high quality collections (i.e., more than five populations per taxon), at the country level, on average only 12% of the taxa met ENSCONET standards (ENSCONET, 2009a). The proportion of high-quality collections may be even lower, as we cannot exclude multiple accessions from the same population (see Methods). Furthermore, only 30% of the taxa were stored with a sufficiently high seed quantity, which clearly limits the use and therefore the utility of the collections. While our results are congruent with former studies (Carta et al., 2025; Godefroid et al., 2011; Liu et al., 2020; Rivière & Müller, 2018), they demonstrate the difficulty of meeting the standards, particularly for rare taxa, which often have very small population sizes or poor seed production. Moreover, seed collection must not threaten the donor populations (Bucharova et al., 2025), further constraining the quantity of seed that can be collected. Despite these challenges, we do advocate that a majority of taxa should be stored as high-quality collections according to ENSCONET standards to allow immediate use of seeds not only for conservation but also for research and teaching. Re-collecting larger populations over multiple years, for instance, may not only allow an increase in seed quantity but will also conserve evolutionary dynamics (Mattana et al., 2025).

In general, the quality of collections follows the general trend of taxonomic coverage: countries that invest a lot in seed banking of wild taxa also tend to exhibit a higher quality of collections. There are, however, some exceptions: Estonia, for instance, has a rather high genetic representation of a relatively low number of taxa, but these are mostly common and commercially used species with low conservation value. Luxembourg, on the other hand, has a relatively well-represented taxa coverage and one of the highest levels of genetic representations per country. While it is undoubtedly easier for countries with a less diverse flora and hence a smaller number of red-listed taxa to preserve their threatened flora, the example of Spain shows that even highly diverse countries can achieve very substantial levels of both coverage and genetic representation of their flora in seed banks when adequate infrastructure is provided.

## 4.4 | Post 2020: How To Move Forward

### 4.4.1 | Perspectives for GSPC Target 8

Although the latest version of the GSPC accompanying the Global Biodiversity Framework (GBF) does not specify its objectives with clear thresholds (CBD, 2024), Target 8 and its 75% threshold from 2020 still represent an important benchmark for the conservation community. Based on our estimation, countries would on average require at least an additional 18 years (from 2020 on) to achieve GSPC Target 8. This estimate is likely rather optimistic for several reasons: First, it assumes a constant number of red-listed taxa collected annually, an assumption that is typically not met. The more red-listed taxa are collected for a seed bank, the more difficult it is to sample new taxa, as the easy-to-collect ones are typically stored first. Secondly, countries that did not participate in our survey, and which probably have very low or no seed banking activity of wild species, were excluded from this calculation. Finally, our calculation aimed to preserve one seed lot per country and did not take into account the recommendation for genetic representativeness and seed quantity (≥5 populations and ≥5000 seeds, ENSCONET, 2009a). Altogether, this shows that a 'business as usual' strategy will delay the appropriate safeguarding of our wild flora for decades, bearing the risk that many populations and even some species may have already entirely disappeared by then (Hochkirch et al., 2023; Kempel et al., 2020). At the same time, currently common species will continue to decline and become red listed in the near future, creating further demand for ex situ conservation in coming decades.

### 4.4.2 | The example from Belgium

This study aimed to assess past progress and to anticipate future trajectories to provide a vision for the continued seed banking of wild plants. The example from Flanders shows how significant progress can be achieved in a relatively short time through the effective use of a network of volunteer seed collectors. Given the outstanding results achieved, the seed bank intends to continue this partnership to obtain similar outcomes and achieve GSPC Target 8 for the southern half of the country (Walloon region). The total budget for the project was 165,000 EUR over 4 years, which is modest when compared with well-known funding schemes for conservation, for instance the EU Life program (https://cinea.ec.europa.eu/programmes/life_en). Collaboration with unpaid nonprofessionals requires training and close supervision. However, it can also raise awareness of seed banking and threatened species among stakeholders with diverse professions and backgrounds, promoting engagement from sectors that usually have limited contact with seed conservation. Such collaborations can therefore have a considerable outreach effect in addition to their direct impact on the conservation of a species. At Meise Botanic Garden, this project was implemented in collaboration with a local NGO and a volunteer network, but research institutions, botanical associations, environmental offices or freelancers could also be involved. An increasing number of countries are relying on coordinated and trained networks for their seed collection, for instance Luxembourg or Switzerland, where part of the collections is carried out by paid professionals.

## 5 | CONCLUSIONS

We have provided a state-of-the-art overview on wild and threatened plant taxa conserved in seed banks across 44 countries together with a perspective on how to meet conservation targets and to implement a realistic seed collecting strategy for the future. Our results demonstrate clearly that under a business-as-usual strategy, it will take too long to safeguard threatened taxa at both national and continental (Europe) levels. This will not only represent a dramatic failure of conservation efforts but also a significant loss of genetic resources potentially useful for agriculture and research (Li & Pritchard, 2009; Liu et al., 2023; Ribeiro et al., 2016).

Using the example of Flanders in Belgium, we showcase that considerable success can be achieved with modest financial investment when the sampling efforts are supported by a trained network of committed seed collectors. However, even volunteering is not independent of financial resources and its effectiveness may vary across countries and cultures (Voicu & Voicu, 2009). Moreover, comprehensive and coherent inter-institutional databasing and prioritization are needed to fill the gaps and facilitate genetic representation across distribution ranges or phylogeny (Carta et al., 2025; Gargiulo et al., 2025), but this does not come without a cost either, as does the maintenance of banked collections such as regular quality testing or seed regeneration (De Vitis et al., 2020). We therefore advocate that strategic political goals should always be accompanied by specific funding schemes ensuring their practical implementation. We consider this a promising way forward, as seed banks alone will not be able to meet conservation targets within the necessary time frames.

## AUTHOR CONTRIBUTIONS

Andreas Ensslin and Sandrine Godefroid conceived the study and collected the data. Andreas Ensslin, Sandrine Godefroid, Adelaide Clemente, Udayangani Liu, Elke Zippel and Carolina Sanchez Romero processed the data and helped harmonize the nomenclature. Andreas Ensslin analysed the data and wrote the first version of the manuscript with the help of Adelaide Clemente, Sandrine Godefroid, Udayangani Liu, Carla Pinto-Cruz, Carolina Sanchez Romero and Simone Schneider. All other authors contributed data and to the final version of the manuscript.

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## CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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