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APPLICATION ARTICLE

Advancing the science and practice of rare plant conservation with the Center for Plant Conservation Reintroduction Database

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Abstract

Premise: Reintroductions or translocations are an increasingly important activity to recover and conserve at-risk plant species. Yet because many are not published in the scientific literature, learning from previous attempts may often require considerable time and effort. The Center for Plant Conservation Reintroduction Database (CPCRD; https://saveplants.org/reintroduction-database/), a new centralized and standardized repository of U.S.-based plant reintroductions, aims to improve the efficiency and effectiveness of accessing data on rare plant reintroductions.
Methods: The CPCRD is the product of multiple efforts to assemble information on rare plant reintroductions in the United States. The database comprises a wealth of standardized data on the key stages of a reintroduction, from the planning and implementation phases, to monitoring and management techniques.
Results: The CPCRD is a dynamic resource, allowing data contributors to continually update their entries as projects progress. While contributions are ongoing, the CPCRD currently includes 460 projects involving 201 plant taxa, spanning diverse growth forms, ecosystems, and regions.
Discussion: The CPCRD and its well-documented and monitored projects provide a valuable practical resource for conservation practitioners, and have supported multiple scientific studies and contributed to the internationally recognized Center for Plant Conservation Best Practices Guidelines.

KEYWORDS
conservation, endangered species, population restoration, threatened species, translocation

A recent global assessment estimates that 39% of all vascular plant species are threatened with extinction in the wild (Nic Lughadha et al., 2020). As threats from anthropogenic climate change, habitat degradation, exploitation, and the spread of invasive species and diseases continue to intensify worldwide (Díaz et al., 2019), a reliance on conventional conservation measures (e.g., habitat protection and management) will be insufficient to prevent species extinctions. Reintroductions and other types of conservation translocations, which involve the intentional movement and release of organisms for the purposes of conservation, have become an increasingly utilized tool in the urgent struggle to save species and restore ecosystems (e.g., Vicente Moreno et al., 2017; Silcock et al., 2019; Abeli et al., 2021). Growth in the practice of reintroductions has been supported by continual advances and refinements in the science of the technique (e.g., Falk et al., 1996; Maschinski et al., 2012; Maschinski and Albrecht, 2017). Despite these positive developments, keeping track of reintroduction methodologies and their associated outcomes has remained somewhat haphazard, because relevant documentation is scattered widely, or remains in unpublished reports (Godefroid et al., 2011; Lesage et al., 2020).

Most plant reintroductions are not published in the scientific literature because they have been implemented as practical conservation actions and may not address specific research questions required by peer-reviewed journals. If information on unpublished projects is not stored and shared appropriately, there is a risk that valuable data will be lost due to the typically high staff turnover rate of some organizations involved in reintroductions (Lesage et al., 2020). Projects that are published often only report short-term milestones (≤3 years) such as survival and reproduction of the founder plants (Godefroid et al., 2011). For unsuccessful projects, locating useful documentation is even more challenging (Abeli and Dixon, 2016) due to publication biases and an overall reluctance towards sharing negative results. Consequently, gaining a comprehensive understanding of what, where, and how reintroductions are being implemented, and whether they are actually delivering meaningful conservation benefits, can be a cumbersome and time-consuming task. As a potential solution to these challenges, several peer-reviewed studies have called for the creation of an accessible online repository for reintroduction information (Godefroid and Vanderborght, 2011; Liu et al., 2015; Lesage et al., 2020; Doyle et al., 2023).

A centralized database can make a significant contribution to the plant conservation community by organizing and standardizing data on the planning, implementation, and monitoring of reintroductions and making this information available to facilitate research and evidence-based conservation (Sutherland et al., 2004, 2010). National web-based plant reintroduction databases have recently been developed in Australia (Silcock et al., 2021), Italy (Abeli et al., 2021), and Spain (Vicente Moreno et al., 2017), providing valuable information on the conservation strategy and policy applied at the country level. In the United States, the Center for Plant Conservation (CPC), a network of over 70 botanical gardens and other conservation nonprofits, has played a leading role in advancing science-based best practices in rare plant reintroductions. The publication and progressive refinement of the CPC Best Practice Reintroduction Guidelines (Falk et al., 1996; Maschinski et al., 2012; Maschinski and Albrecht, 2017; Center for Plant Conservation, 2019) was made possible through the collective experience of the CPC network, which has been involved in hundreds of rare plant reintroductions to date. Many of these reintroductions have been conducted as experiments to fill gaps in knowledge about the species' biology or ecology (Maschinski et al., 2013; Menges et al., 2016; Wendelberger and Maschinski, 2016). In the process, these projects have generated an abundance of practically and scientifically valuable information, from the initial planning, preparation, and implementation to the subsequent monitoring and aftercare.

Here, we present the Center for Plant Conservation Reintroduction Database (CPCRD), an accessible web-based repository and continually expanding database of rare plant reintroductions and other forms of conservation translocations conducted in the United States (Video 1). The CPCRD represents the aggregation and harmonization of multiple efforts to assemble standardized information on U.S. rare plant reintroductions (Guerrant, 2012; Albrecht et al., 2019). The database includes projects that have occurred on a broad range of species, sites, and ecosystems, and is intended for use by both scientists and practitioners as part of ongoing efforts by the CPC to refine best practices in rare plant reintroduction. For scientists interested in harnessing the CPCRD for research, the database is designed to support investigations into a variety of contemporary research questions based on, for example, the effectiveness of different

VIDEO 1 Introducing the Center for Plant Conservation Reintroduction Database. This video provides a brief introduction to conservation reintroductions, the types of information collected in the database, and how this information is gathered and accessed.

management practices for long-term reintroduction success (Whitehead et al., 2023), climate change adaptation in reintroductions (Moehrenschlager et al., 2022), and the evaluation of geospatial factors for understanding long-term reintroduction success (e.g., Bellis et al., 2020; Skikne et al., 2020). In addition to the research potential of the CPCRD, the database aims to provide access to the following benefits for reintroduction practitioners: (i) useful information on hundreds of mainly unpublished reintroductions in a standardized format, (ii) a dynamic resource where reintroduction project data can be continually updated over the lifespan of a project, (iii) institutional memory of an organization's reintroduction records, and (iv) participation in diverse collaborations through the promotion of an inclusive co-authorship policy.

METHODS

Definitions and data collection

The CPCRD uses the term "reintroduction" in the broadest sense to describe the deliberate movement or introduction of plant material to an area with the aim of establishing a viable natural population and reducing a species' risk of extinction. All four types of conservation-motivated reintroductions or "translocations" defined by the International Union for Conservation of Nature (IUCN) are eligible for inclusion in the database: reinforcements, reintroductions, assisted colonizations, and ecological reinforcements (IUCN/SSC, 2013). Reintroduction is defined as "the intentional movement and release of an organism inside its indigenous range from which it has disappeared"; reinforcement is "the intentional movement and release of an organism into an existing population of conspecifics"; assisted colonization is "the intentional movement and release of an organism outside its indigenous range to avoid extinction of populations of the focal species"; and ecological replacement is "the intentional movement and release of an organism outside its indigenous range to perform a specific ecological function." The CPCRD organizes projects by species (and recipient site, see below for guidance on splitting by site), but reintroductions of multiple rare plant species to a site (e.g., community translocation) are also eligible if the data are submitted individually for each species. The CPCRD does not include projects that were conducted for commercial purposes (e.g., for subsequent harvesting) or with no clear conservation-related objective. Projects where propagules were outplanted purely for experimental purposes, such as reciprocal transplant experiments, common garden experiments, or survival experiments in artificial ecosystems are ineligible. However, submissions of reintroduction projects that, in addition to establishing a viable population, also aimed to experiment with different treatments (e.g., Peterson et al., 2013; Menges et al., 2016), are eligible and encouraged.

To maintain consistency and to facilitate future comparative analyses, two rules of thumb were adopted to determine whether reintroductions qualify as single or multiple separate projects in the CPCRD:

1. Spatial proximity rule (adapted from NatureServe's 2004 Habitat-based Plant Element Occurrence Delimitation Guidelines; NatureServe, 2020): (a) Distinct units that are <1 km apart should be collapsed into a single reintroduction or other conservation translocation project. (b) Distinct units that are 1–10 km apart should be considered single or separate projects depending on the species biology, project goals, and habitat. (c) Distinct units that are >10 km apart should be considered as separate projects.
2. Experimental treatments rule: Collapse all experimental treatments at a site into a single reintroduction or other conservation translocation project unless they can be considered as separate projects based on the spatial proximity rule above. The database captures information on treatments or interventions in another section (see section 1.5.5 of Appendix S1 for full list of options).

Prior to the inception of the CPCRD, we gathered and standardized U.S.-based reintroduction data from multiple sources, starting with the CPC International Reintroduction Registry (CPCIRR) (Guerrant, 2012) and the collection of projects described in Bellis et al. (2024). Both data sets held information on a large number of unpublished reintroductions, which tend to be less biased towards the most successful projects (Godefroid et al., 2011). The CPCIRR documented 145 plant reintroductions, mainly in the United States, and included at least basic taxonomic, location, management technique, and data source information. After excluding ineligible projects and projects outside of the geographical scope of the CPCRD, 97 reintroductions from the CPCIRR were retained. The REDCap data set described in Bellis et al. (2024) held information on 275 reintroductions and collected standardized data on project implementation, monitoring outcomes, practitioner's perceptions of success and failure, and species traits. Before incorporating this data set into the CPCRD, we contacted each participant to request their permission to access and include their entries; most participants granted us permission to transfer their records ($n = 252$, including 39 projects that overlapped with the CPCIRR). We also obtained data on more than 100 new reintroductions through communication with CPC conservation partners and contributors of the CPCIRR and REDCap data sets (e.g., Wooten et al., 2020), as well as through reference lists from articles already in the CPCRD (e.g., Giles-Johnson et al., 2011).

Database structure

The CPCRD is organized into 56 fields of information that are structured into six field types: participant information, reintroduction project description, taxon information, source selection and outplanting, monitoring and management, and status and performance (see Appendix S1 for a full list of fields). Fields were selected and designed according to international and national guidelines (IUCN/SSC, 2013; Maschinski and Albrecht, 2017) and with inspiration from preceding U.S.-focused plant reintroduction data collection efforts (Guerrant, 2012; Albrecht et al., 2019).

(With the CPCRD now live https://saveplants.org/reintroduction-database/), new projects populate a MySQL database with a standardized field vocabulary through the submission of the primary Reintroduction Project Submission Form on the CPC website. Data submitted via the primary submission form populate a parent table, while information from outplanting and monitoring events is collected from two secondary submission forms and populated in separate child tables. All tables are connected through a consistent Project ID field. This functionality allows the CPCRD to operate as a dynamic resource, with contributors able to update their own entries as new outplanting and monitoring information is acquired (Figure 1). For example, if a practitioner has outplanted new propagules at a recipient site since the last data submission, this information can be added to the existing database entry via the submission of an Outplanting Event Form. Similarly, if additional monitoring or management data has been collected, this can be added to the entry by submitting a Monitoring Event Form (see Appendix S1 for list of fields in each form). In the future, longitudinal data from periodic outplanting and monitoring or management events could inform time-series analyses aimed at understanding the impacts of management and changing environmental conditions across a large number of reintroduced populations.

A subset of the fields in the CPCRD, including taxon name, project type, state, lead institution, and conservation status, is presented for public access and download on the CPC Reintroduction Registry (https://saveplants.org/reintroduction-registry/). This summary page contains all of the projects in the CPCRD and allows practitioners to evaluate the contents of the CPCRD before submitting an access request or contributing a record.

Optimizing the database

The CPC national meetings held in May 2022 and 2023, where hundreds of delegates from across the CPC network gathered to share information on rare plant conservation, were used as a platform to promote the CPCRD project, encourage contributions, and gather feedback from potential contributors. At the 2022 meeting, we focused on the identification of reintroduction projects and the coarse-scale cataloging of these projects for inclusion in the public-facing CPC Reintroduction Registry. In 2023, we encouraged new and updated database submissions and received feedback from participants in order to optimize the project submission process and the overall user experience. We sought feedback from attendees on site and via a post-submission survey form,

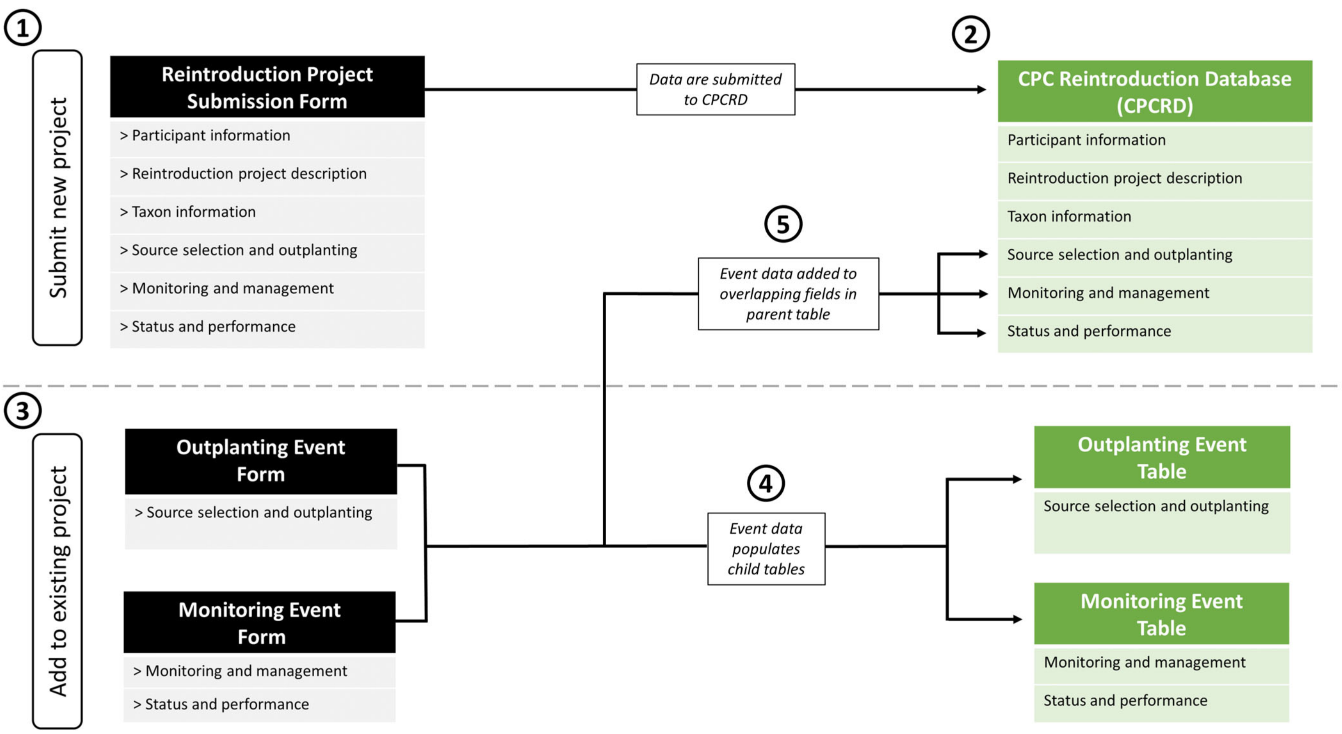

FIGURE 1 Overview of the data submission processes for the Center for Plant Conservation Reintroduction Database (CPCRD). After submitting a new project using the primary Reintroduction Project Submission Form (1), the information is stored and displayed as an entry in the CPCRD (the parent table) (2). Entries can be added to by completing one of the secondary outplanting or monitoring event forms (3). Event data are stored in the corresponding child table (4), and are also added to overlapping fields in the parent table (5). The complete arrangement of fields in each form and table is detailed in Appendix S1.

which contained 12 questions about the CPCRD submission process, the utility of the CPCRD, and suggestions for incentivizing future data contributions.

CPC launched a small grant program for database contributors following the 2023 National Meeting. Our goals were to (1) incentivize testing of the platform for user experience and bug detection and (2) educate prolific reintroduction practitioners in the United States on how to submit and update projects in the database to increase their likelihood of using the resource in the future. We granted CPC member institutions US$50 per new reintroduction project submission or US$50 per comprehensive update of monitoring and outplanting records for an existing project for a minimum of six projects. While we do not intend for future submissions to this resource to originate from direct monetary support from CPC, we wanted to provide a "carrot" for early adopters of this new technology to help recognize the work of learning and debugging a new system. As a direct result of this grant, we received 67 new reintroduction submissions or project updates to the CPCRD between June and October 2023, and partners involved in this pilot program made an additional 26 unfunded submissions.

Data protection and usage

In order to protect sensitive information, viewing and downloading contents of the CPCRD is restricted to vetted individuals. Access to the database is arranged by obtaining "vetted data contributor status," which is attainable through the submission of a reintroduction project and granted by the CPC National Office. Individuals from an institution that has contributed data to the CPCRD are eligible for the same permissions as the original data contributor, allowing them to edit or add information to projects led by their institution. To maximize the utility of the database, individuals who are planning a reintroduction can also apply for access as a "future contributor" by registering the name of the taxon they intend to reintroduce. This type of access grants the individual one year of view-only access to the entire database. Data from the CPCRD may also be shared with scientists who have not contributed to the database but are interested in utilizing the resource to conduct analyses. Because some rare species are subject to poaching or other forms of exploitation, location-related information (e.g., the coordinates of the recipient and source locations) is restricted to the original data contributor, members of their institution, and database managers at the CPC National Office.

The data usage policy of the CPCRD requires that authorship be offered to all vetted data contributors whose records are included in a post-hoc analysis or research study targeting an external audience, including peer-reviewed articles, white papers, and commissioned reports. We believe this promotes the scientific integrity of research by giving credit where credit is due, while also encouraging collaborations between data contributors and scientists interested in utilizing the platform.

RESULTS

On 14 July 2023, the CPCRD contained information on 460 projects involving 201 taxa across 33 orders. A majority of reintroduced taxa with designated NatureServe global conservation statuses ($n = 193$) were classified as Critically Imperiled (G/T1; 47%), Imperiled (G/T2; 21%), or Vulnerable (G/T3; 18%). Projects in the CPCRD outplanted a diversity of growth forms (Figures 2, 3), although particular attention was given to herbaceous taxa, with almost half of all projects focusing on this group (49%); while 23% of projects planted woody shrubs; 10% planted trees; 7% planted cacti/succulents; 5% planted subshrubs or suffruticose shrubs; 4% planted vines; 2% planted ferns; <1% planted graminoids; and a single project, involving *Polytrichum appalachianum* L. E. Anderson, planted a nonvascular species (Figure 3). In the state of Hawaii, practitioners tended to focus on the reintroduction of woody shrubs and trees, which accounted for 47% and 89%, respectively, of all projects conducted on these groups within the United States. *Styrax platanifolius* Engelm. ex Torr. subsp. *texanus* (Cory) P. W. Fritsch, a woody shrub endemic to the state of Texas, represents the taxon with the most reintroductions in the database, having been outplanted at 22 sites. Projects with information on ecosystem type ($n = 299$) revealed that reintroductions were most commonly conducted in forest (36%) and savanna and shrub-steppe (23%) ecosystems, while a similar percentage occurred in herbaceous wetlands (9%), woody wetlands or riparian habitats (9%), upland grasslands (8%), upland shrublands (8%), and sparsely vegetated (7%) ecosystems.

The database covers a period of 53 years, with the oldest project involving *Echinacea tennesseensis* (Beadle) Small (Figure 2I), a herbaceous perennial species endemic to the state of Tennessee that was first reintroduced in 1970. The temporal distribution of projects in the CPCRD indicates consistent growth in the number of plant reintroductions being undertaken in the United States (Figure 4). In populations recorded as extant, the average number of annual monitoring events since initial outplanting was six (maximum = 27, $n = 304$), while the average year of most recent monitoring was 2014 (oldest record = 1992). In cases where the project type was defined ($n = 439$), reintroductions into sites within the indigenous range (72%) and reinforcements of existing populations (26%) were most common, while assisted colonizations beyond the indigenous range (2%) were undertaken less frequently and there were no examples of ecological replacement. Projects with information on stakeholder involvement ($n = 316$) indicated that federal government (73%), university/research institutes (54%), and state government (51%) were most frequently involved in rare plant reintroductions, followed by botanic gardens with ex-situ plant collections (37%) and nonprofits (26%), while projects involving local government (9%), private individuals (6%), corporations (2%), local community groups (1%), and aboriginal/First Nations/

FIGURE 2 Examples of reintroduced taxa demonstrating the diversity of projects stored in the Center for Plant Conservation Reintroduction Database. (A) *Abronia umbellata* subsp. *breviflora*, (B) *Astragalus michauxii*, (C) *Erythrina sandwicensis*, (D) *Pseudophoenix sargentii*, (E) *Calochortus umpquaensis*, (F) *Sarracenia purpurea* var. *montana*, (G) *Ziziphus celata*, (H) *Potentilla robbinsiana*, (I) *Echinacea tennesseensis*, (J) *Pinus torreyana* subsp. *torreyana*, (K) *Ipomopsis sancti-spiritus*, (L) *Sesbania tomentosa*, (M) *Jacquemontia reclinata*. Photos used with permission from: (A) Tom Kaye, (B, F) Michael Kunz, (C) Emily Grave, (D) Kristie Wendelberger, (E) Kris Freitag, (G) Cheryl Peterson, (H) Doug Weihrauch, (I) Matthew Albrecht, (J) San Diego Zoo Wildlife Alliance, (K) Joyce Maschinski, (L) Peter Van Dyke, (M) Sam Wright.

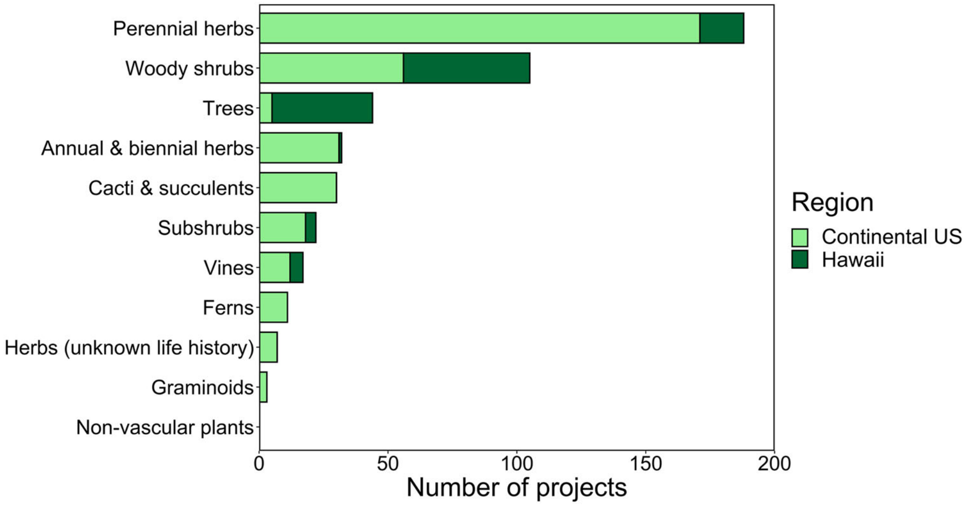

FIGURE 3 Number of rare plant reintroductions conducted in the continental United States and Hawaii on each growth form ($n = 460$).

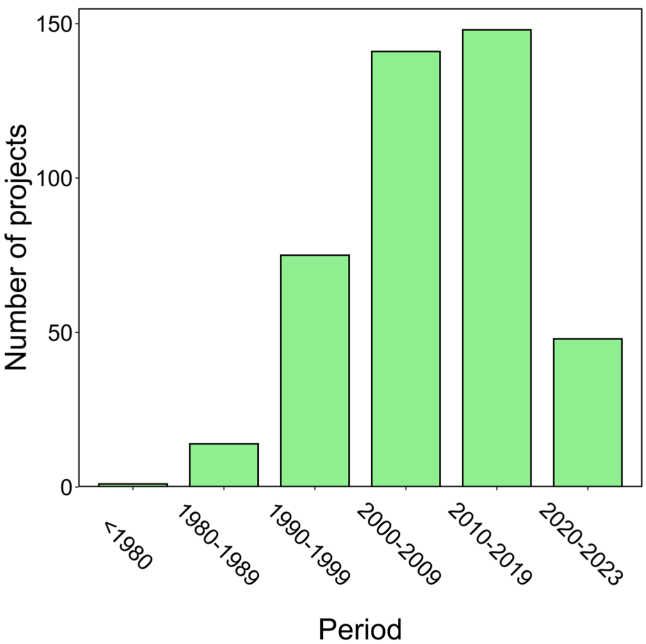

FIGURE 4 Number of rare plant reintroductions carried out in the United States since the first documented project in 1970 ($n = 443$).

indigenous groups (<1%) were less frequently observed. Most projects where the land ownership and protection status were known ($n = 298$) were located in public protected areas (85%), with fewer projects located on private land within protected areas (10%), and very few projects that were located outside of protected areas (public = 3%, private = 1%) or on sites with mixed land ownership (1%). The database includes reintroductions from 28 U.S. states, with the highest concentrations in Hawaii ($n = 115$) and Florida ($n = 93$), followed by Oregon ($n = 39$), Kentucky ($n = 37$), Texas ($n = 31$), and California ($n = 25$) (Figure 5).

DISCUSSION

The establishment of the CPCRD fills a key gap in the digital storage and sharing of rare plant reintroduction data in the United States. Historically, detailed information about rare plant reintroductions was difficult or impossible to access unless an individual was working directly with a specific project (Lesage et al., 2020). Now, with a centralized database, the plant science and conservation community has a permanent digital repository to store and share reintroduction data, as well as access to standardized data on over 400 projects spanning diverse growth forms (herbaceous to woody), ecosystems (forests to grasslands), and regions (tropical to temperate). With 77% of recovery plans recommending reintroduction for threatened and endangered plants protected under the U.S. Endangered Species Act (ESA), the CPCRD can play a vital role in advancing the conservation of at-risk species.

Trends in reintroduction practice

Our overview of projects in the CPCRD shows how plant reintroductions are temporally, taxonomically, and spatially distributed in the United States. At present, the CPCRD is not a comprehensive representation of U.S. plant reintroductions because the data acquisition methods implemented hitherto have not attempted to exhaustively catalog U.S.-based reintroduction efforts (but see section below on growing the database). Nonetheless, some of the broad trends emerging from the CPCRD are consistent with national plant reintroduction databases in Europe and Australia (Vicente Moreno et al., 2017; Silcock et al., 2019; Abeli et al., 2021), such as the growing use of reintroductions in recent decades and the low representation of certain growth forms (e.g., non-vascular plants). Relative to the size of the reintroduction databases in Italy (IDPlanT, $n = 185$

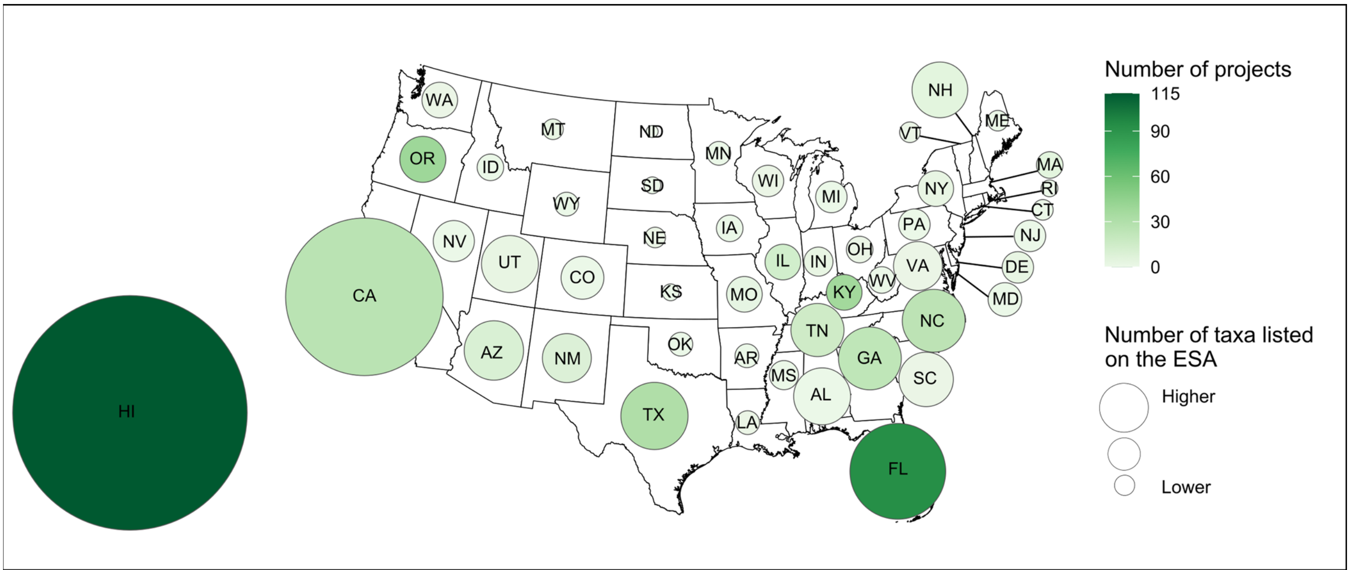

FIGURE 5 Number of rare plant reintroduction projects and taxa listed on the Endangered Species Act (ESA) by state (excluding Alaska, which had zero entries to the Center for Plant Conservation Reintroduction Database at the time of publication). Darker shading indicates a greater number of reintroductions while a larger circle size indicates a greater number of taxa listed on the ESA (minimum–maximum = 1–390).

[Abeli et al., 2021]) and Spain (Trans-Planta, $n = 330$ [Vicente Moreno et al, 2017]), the CPCRD holds data on a substantial number of projects ($n = 460$), but notably less than the Australia-focused database (Australian Plant Translocation Database, $n = 1182$ [Silcock et al., 2021]). Although this difference may be attributed in part to variation in data collection methods and project eligibility criteria, another significant source of variation likely stems from the large number of mitigation-driven projects in Australia, which account for 30% of all documented reintroductions (Silcock et al., 2019), compared with just three cases in the CPCRD. A review of animal mitigation translocations suggests that projects in the United States tend to have lower accessibility and documentation than other types of conservation-driven translocations (Germano et al., 2015).

Overall, herbaceous taxa are the most represented growth form in the CPCRD, but there is considerable geographical variation between the continental United States and Hawaii. For example, herbaceous taxa account for 61% of reintroductions in the continental United States compared with just 16% of reintroductions in Hawaii. Instead, projects in Hawaii concentrated more on woody shrubs and trees, which accounted for 77% of reintroductions (compared with 18% in the continental United States). Hawaii's focus on woody plants aligns more closely with reintroduction practices in Australia (Silcock et al., 2019) and reflects the differences in conservation need between herbaceous and woody taxa in the tropics versus the more temperate climates of the continental United States (Humphreys et al., 2019). Given the relatively large number of fern and allied taxa from the United States that are listed on the ESA ($n = 33$), this group may be underrepresented in the CPCRD relative to the number of projects being undertaken (11 projects on eight taxa). However, the paucity of projects on nonvascular plants ($n = 1$) reflects the wider lack of awareness and conservation attention given to this group (Cornwell et al., 2019), for which only one species is listed on the ESA.

The spatial distribution of projects in the CPCRD closely aligns with the findings of a comprehensive review of North American animal translocations (Brichieri-Colombi and Moehrenschlager, 2016), where the northwestern and southeastern United States, in particular the states of California, Florida, Oregon, and Texas, are emerging as hotspots of reintroduction activity for both animals and plants. As was suggested for animal reintroductions, plant reintroduction activity appears to correspond with regional hotspots of species richness, endemism, and at-risk status because these states generally have large native floras and high levels of endemism and rarity (Stein and Gravuer, 2008). In particular, the number of taxa listed under the ESA appeared to correlate with the number of rare plant reintroduction projects, as six of the top eight states for threatened or endangered taxa also ranked in the top eight for reintroductions. The two exceptions to this trend were Oregon and Kentucky, which ranked 15th and 19th for number of taxa listed under the ESA, but contributed the third and fourth most projects to the CPCRD, respectively. Western states such as Arizona ($n = 9$) and Utah ($n = 2$) were poorly represented in the database relative to the size of their native floras and the number of at-risk species (Stein and Gravuer, 2008). While disparities in funding support may explain some of the state-level variation in reintroduction activity, differences in how states store reintroduction information are also a likely contributing factor. For example, in the state of Kentucky, reintroduction data are held in a centralized database, which facilitated the efficient transfer of records on 36 reintroduction projects, even though these projects were led by 11 different institutions. As we continue to disseminate the CPCRD, we expect the Western United States, as well as other states with large native floras and high numbers of at-risk plant taxa (e.g., Alabama), to increase in representation.

The CPCRD as a scientific resource

Most published studies base reintroduction success on short-term performance measures of the founder population (e.g., survival and reproduction) (Menges, 2008). However, short-term benchmarks can be misleading when trying to infer future growth and viability because the factors that promote establishment may differ from those required for long-term persistence (Iles et al., 2016). In this section, we illustrate how the CPCRD is informing two research studies aiming to advance the science and practice of rare plant reintroduction through improving our understanding of the factors influencing long-term success.

In a recent study (Bellis et al., 2024), data available in the CPCRD were used to identify the most important site attributes, management techniques, and species traits for six life-cycle benchmarks (e.g., next-generation recruitment) and population metrics (e.g., population size) of reintroduction success. The results showed that management techniques (such as founder size) had the greatest relative influence on the attainment of life-cycle benchmarks and short-term population trends, while site attributes (such as habitat quality change) and species traits (such as lifespan) were more important for population persistence and longer-term trends. This study demonstrated that by combining long-term monitoring with adaptive management, reintroduction programs can enhance their prospects of achieving long-term success. The findings of this research were made possible through the assembly of a large ($n = 275$), well-documented, and well-monitored (nearly 8 years on average) data set of reintroductions.

In a second, ongoing study, a novel suite of geospatial predictor variables was constructed from two locational fields in the CPCRD and analyzed to understand the importance of spatially heterogeneous environmental factors for rare plant reintroduction success (LocationRecipientSite and LocationSourcePopulationSites, see Appendix S2 for descriptions of a subset of the geospatial variables and their hypothesized effects on reintroduction success). These factors are sometimes underestimated in reintroductions, with recipient sites selected based on subjective judgements of habitat quality, or the historical presence of the species, disregarding recent or potential future changes in the environment (Osborne and Seddon, 2012). Geospatial predictors were categorized into three independent groups—depending on whether they provided insight on the importance of the source population, the orientation of the recipient site, or spatial traits of the focal species—for understanding reintroduction success (defined according to the attainment of intergenerational benchmarks and population persistence). Predictors were selected according to well-established ecological theories and hypotheses, such as the importance of local adaptation for source population selection (McKay et al., 2005), the utility of the center-periphery hypothesis for recipient site selection (Brown, 1984), and the importance of niche breadth for species selection (Vincent et al., 2020) (Appendix S2). To aid reintroduction practitioners in determining the level of prioritization that these geospatial variables warrant, more conventional predictors identified as important in Bellis et al. (2024), such as founder size and the number of source populations, were also incorporated into the analysis.

The CPCRD as a practical resource

Web-based documentation was available for 30% of reintroduction projects in the CPCRD, while just 13% of projects were published in the peer-reviewed literature. From a practitioner's perspective, the amount of useful information that can be extracted from these sources varies dramatically; in the case of peer-reviewed articles, journals prioritize manuscripts that focus on particular hypotheses, relating to, for example, the implications of inbreeding (e.g., Kephart, 2004) or the trial of a particular management strategy (e.g., Devine et al., 2007). Consequently, peer-reviewed articles seldom contain detailed information on the techniques used or the results obtained (Godefroid and Vanderborght, 2011). Even in the case of more detailed project reports or academic theses, much practically valuable data are often missing (e.g., information on source populations) and may be at risk of loss without thorough recordkeeping, especially if the individual moves to another organization (e.g., Lesage et al., 2020).

The CPCRD addresses these barriers to accessing, sharing, and storing standardized data on reintroductions that have limited the conservation community's ability to apply lessons learned from previous projects. During the project planning stage, the search functionality of the CPCRD can help practitioners (with future contributor status, see section on Data Protection and Usage, above) find the most successful method to apply depending on the biological traits of the target species and the characteristics of the recipient ecosystem. If a practitioner wishes to access further information on a particular project, they can check the associated notes and references, or use the contact information stored in the CPCRD to connect directly with the contributor, facilitating the exchange of knowledge, expertise, and potential collaborations. During the monitoring and management stage, practitioners can review cases where others have encountered a similar threat (e.g., a problematic native species) or applied a particular management intervention (e.g., herbivore exclusion). For practitioners wishing to contribute data, the database provides a platform to share their reintroductions without the constraints imposed by scientific journals, while still providing a potential route to peer-reviewed publication through the database's inclusive co-authorship policy (e.g., Bellis et al., 2024).

The CPCRD's ability to function as an archival tool offers benefits for individuals and organizations conducting reintroductions. Studies from the restoration and reintroduction literature have reported cases where documentation of management methodologies was either missing, stored as a hard copy in a filing cabinet, or not recorded at all (Dickens and Suding, 2013; Lesage et al., 2020). Inadequate data recording and storage can cause problems when a staff member leaves an organization because the successor could be missing critical information on management techniques that have been applied or the factors that guided decision-making. However, if the departing staff member entered their project into the CPCRD, the successor can gain access to these records from CPC, ensuring continuity and knowledge preservation. We encourage organizations involved in reintroductions to create a policy for staff to archive projects in the CPCRD.

Growing the database

Determining whether a reintroduced population is sustainable requires decades of long-term monitoring (Maschinski and Albrecht, 2017); however, information on the management and status of reintroduced populations is usually shared shortly (≤3 years) after a project has commenced (e.g., Menges, 2008; Godefroid et al., 2011; Dalrymple et al., 2012). Once this information has been shared, either within the academic or gray literature, or via a survey, it is often the case that the conservation community does not receive any further updates on the reintroduction project. The current assemblage of projects in the CPCRD, which were last updated nearly a decade ago on average, illustrate this issue because most projects were integrated from preceding surveys or the academic/gray literature. However, the CPCRD's designated outplanting and monitoring event forms aim to address this problem by enabling and encouraging contributors to continually update reintroduction records over the lifetime of their projects. As a result, the CPCRD has the potential to facilitate much longer-term assessments of rare plant reintroduction outcomes than what has been possible to date.

The temporal trends of the CPCRD and other national data sets indicate a growing use of plant reintroductions in multiple countries (Vicente Moreno et al., 2017; Silcock et al., 2019; Abeli et al., 2021). In Canada, future projections based on an examination of species recovery plans predict a further two- to three-fold escalation in the use of reintroduction over 10 years (Swan et al., 2018). With reintroduction frequently recommended as a conservation action in recovery plans from the continental United States and Hawaii, increases are also likely to continue across the United States. The CPCRD, designed and managed by a leading U.S. conservation organization with nearly four decades of experience in horticulture, research, and restoration, is well placed to support this growth.

To effectively capture and archive new reintroduction data, we are implementing multiple strategies to increase awareness and adoption of the CPCRD. These include presentations at national (e.g., CPC National Meetings) and international conferences (e.g., the 2022 International Plant Translocation Conference and the 2023 International Conservation Translocation Conference), dissemination through conservation networks and personalized electronic mailing lists, and through the forthcoming publication of peer-reviewed papers. We are also prioritizing outreach to federal, state, and local governments (which fund and permit much of the rare plant translocation work conducted in the United States) through the Plant Conservation Alliance communication channels and through direct outreach to native plant program officials. During the dissemination process, we are especially encouraging the submission of projects on underrepresented growth forms (e.g., ferns) and in underrepresented regions (e.g., the Western United States), so we can learn about what factors are shaping their reintroduction outcomes. We are also calling for the submission of failed projects, which are poorly represented in the CPCRD (population reported extinct, $n = 18$), most likely due to publication biases and an overall reluctance towards sharing negative results (Menges, 2008; Godefroid et al., 2011). Learning from failed attempts through an adaptive management process can improve future reintroduction success (Albrecht, 2022). Readers are invited to share information about additional projects by submitting data on the CPC website (https://saveplants.org/reintroduction-database/), as this will enable the plant conservation community to gain new insights on the practice of reintroduction, both its successes and failures. Finally, given the reluctance of plants to adhere to international borders, we plan to expand the geographical scope of the database to neighboring countries, by working with the CPC's botanical partners in Canada and Mexico.

AUTHOR CONTRIBUTIONS

J.B., K.D.H., M.A.A., and J.M. contributed to the initial design of the study. All authors contributed to the collection of data. J.B. led the exploration of data and the writing of the manuscript. All authors approved the final version of the manuscript.

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DATA AVAILABILITY STATEMENT

In order to protect sensitive information, the contents of the Center for Plant Conservation Reintroduction Database are restricted to vetted individuals. Access to the database is arranged by obtaining "vetted data contributor status," which is attainable through the submission of a reintroduction project and granted by the Center for Plant Conservation National Office.

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SUPPORTING INFORMATION

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

Appendix S1. Field definitions for the Center for Plant Conservation Reintroduction Database.

Appendix S2. Potential geospatial predictors of rare plant reintroduction outcomes.

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