Received: 11 October 2023 | Accepted: 19 February 2024

DOI: 10.1002/aps3.11586

REVIEW ARTICLE

Applications in Plant Sciences

Integrated plant conservation through the Global Conservation Consortia

Jean Linsky[1] | Amy Byrne[2] | Vanessa Handley[3] | Emily E. D. Coffey[1] | Silvia Alvarez-Clare[2,4] | Dan Crowley[4,5] | Abby Meyer[6]

[1]Atlanta Botanical Garden, Piedmont Avenue NE, Atlanta, Georgia 30309, USA

[2]The Morton Arboretum, 4100 Illinois Route 53, Lisle, Illinois 60532, USA

[3]Montgomery Botanical Center, 11901 Old Cutler Road, Coral Gables, Florida 33156, USA

[4]Botanic Gardens Conservation International, Descanso House, 199 Kew Road, Richmond TW9 3BW, United Kingdom

[5]Westonbirt, The National Arboretum, Forestry England, Tetbury, Gloucestershire GL8 8QS, United Kingdom

[6]Botanic Gardens Conservation International-US, at The Huntington Library, Art Museum, and Botanical Gardens, 1151 Oxford Road, San Marino, California 91108, USA

Correspondence

Jean Linsky, Atlanta Botanical Garden, Piedmont Avenue NE, Atlanta, Georgia 30309, USA.
Email: jlinsky@atlantabg.org

This article is part of the special issue "From Theory to Practice: New Innovations and Their Application in Conservation Biology."

Abstract

The 2020 State of the World's Plants and Fungi report revealed that two in five plant species are threatened with extinction. Despite their diverse ecosystem services and myriad human uses, plants receive a fraction of the conservation resources directed at animal taxa. Several existing frameworks—including International Union for Conservation of Nature (IUCN) Specialist Groups, the American Public Gardens Association Plant Collections Network, and the Center for Plant Conservation National Collection of Endangered Plants—have spurred conservation action, but there remains an urgent need to scale up conservation efforts for the world's plants. Here, a new approach to coordinated conservation action for plant taxa is described: the Global Conservation Consortia (GCC). GCC catalyze institutions and experts to collaboratively develop and implement comprehensive strategies to prevent extinction of threatened plant groups. This review focuses on three tree-focused, U.S.-led consortia: cycads, magnolias, and oaks, but the GCC framework is applicable to other taxonomic groups. This review covers consortia design and implementation, provides conservation action case studies, and shares preliminary successes and challenges as this new and exciting approach to conservation is developed.

KEYWORDS

botanical gardens, collections, conservation, global consortia, plants, trees

Biodiversity is in crisis, with over a million species of organisms likely facing extinction and the ongoing decline of species and populations worldwide (IPBES, 2019). International recognition of this crisis and efforts to halt biodiversity loss are most recently laid out in the Kunming–Montreal Global Biodiversity Framework (Stephens, 2023), which was adopted during the Conference of the Parties (COP15) in 2022. This framework acknowledges the importance of biodiversity to support human well-being and life systems on Earth. The State of the World's Plants and Fungi report series highlights the importance of plant biodiversity in particular, and presents the alarming figure of an estimated two in five plant species as threatened with extinction (Antonelli et al., 2020).

As a case study in understanding the threats to plants, the recent State of the World's Trees report (BGCI, 2021) produced via the Global Tree Assessment revealed that one-third of the nearly 60,000 tree species of the world are under threat (IUCN, 2020). That is more than double the number of threatened mammals, reptiles, and amphibians combined (BGCI, 2021). The report highlights regional differences in tree species richness, as well as regions with higher proportions of threatened species (i.e., the Afrotropics) and Not Evaluated and Data Deficient species (i.e., Indo-Malaya) (Figure 1). The main threats to tree species globally are habitat loss, including conversion of land for agriculture and direct exploitation, particularly for timber, as well as impacts from pests, diseases, and climate change (BGCI, 2021). The

work of the Global Tree Assessment has also produced taxon- and region-specific International Union for Conservation of Nature (IUCN) Red List publications, highlighting the threats to certain families or genera and biodiverse regions (e.g., Rivers et al., 2016; Marinho and Beech, 2019; Beech et al., 2020).

Loss of trees can have devastating consequences for ecosystems and human livelihoods, as trees carry out ecosystem services including water and air filtration, erosion prevention, carbon sequestration, and regulation of air quality and temperature. Trees also provide high value products such as timber, medicine, fruit, and nuts. The provision of these vital processes and resources is disrupted when trees are lost. This loss is connected to natural disasters and cascading effects on human life (IPBES, 2019). However, plants in general have received significantly less conservation attention and resources compared to other more charismatic organisms (Gordon et al., 2020; Adamo et al., 2022). In the United States, although the majority of the species listed on the Endangered Species Act are plants, they received less than 5% of the funding for recovery from various federal and state agencies (Negrón-Ortiz, 2014). By way of an international example, the Mohamed bin Zayed Species Conservation Fund—a vital funding resource for global conservation action—has provided US$24 million in support to over 2600 projects since its inception. To date, only 11% of this has been directed at plants, a group with many threatened species, in comparison to 57% directed at mammals, reptiles, and amphibians (Mohamed bin Zayed Species Conservation Fund, 2023). Furthermore, taxonomic capacity and funding have traditionally been concentrated in economically advantaged countries of North America and Europe, yet the preponderance of threatened plant species occur in biodiversity hotspots—megadiverse yet often economically under-resourced regions (Myers et al., 2000; Westwood et al., 2020; IUCN, 2023). Plant conservation has been hindered in some cases by difficult taxonomy (e.g., due to hybridization), making the identification of discrete focal species challenging (Griswold et al., 2018). While working from a taxonomic perspective can allow action to be taken for related species that may have similar needs, the immense number of species in a single genus or family can make prioritization of species most in need of conservation action an overwhelming task.

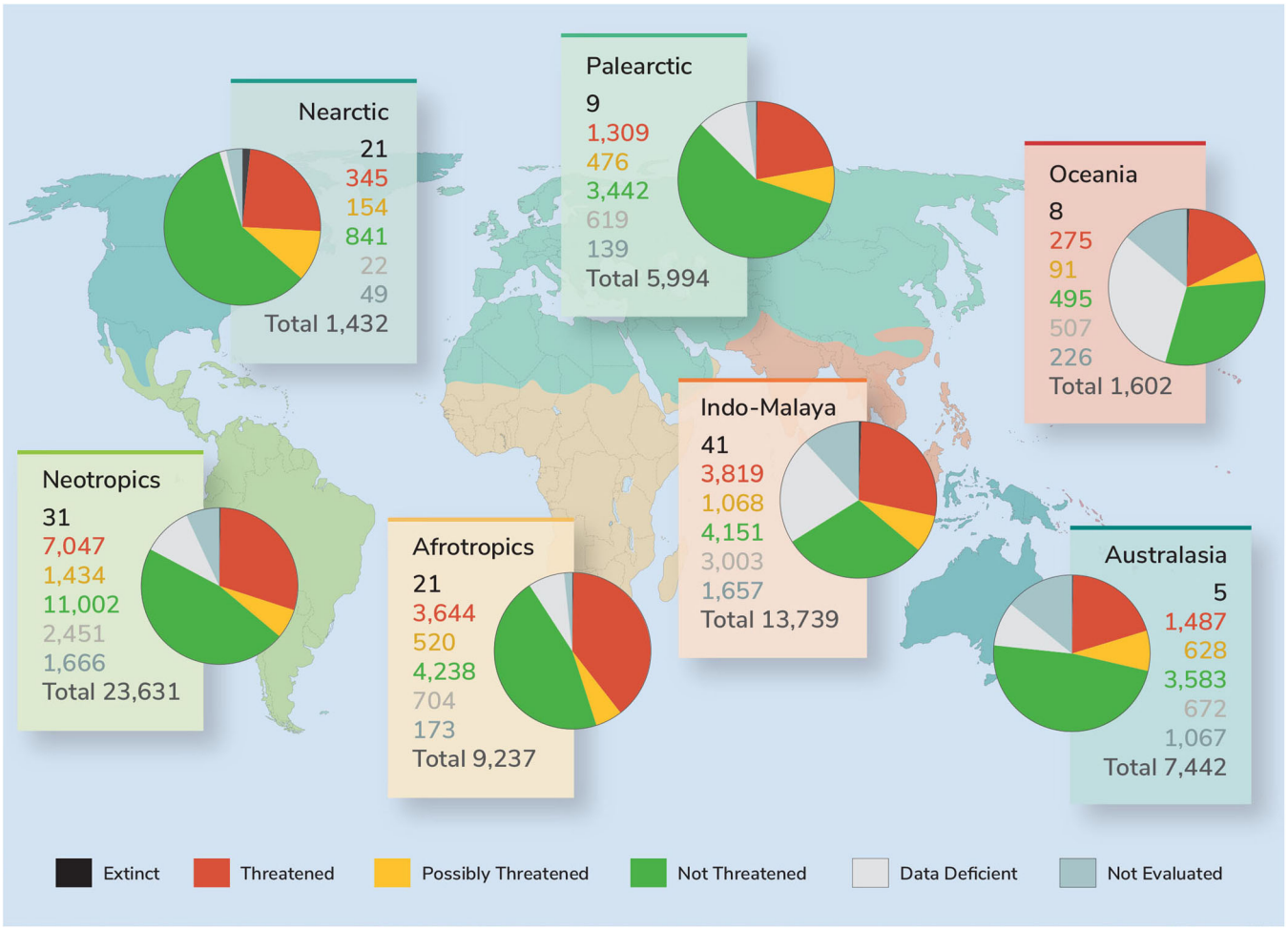

FIGURE 1 The conservation status of the world's tree species, by geographic area. Reprinted with permission from Botanic Gardens Conservation International (BGCI, 2021).

For example, some of the most diverse tree genera (e.g., *Syzygium* Gaertn., *Eugenia* L., and *Eucalyptus* L'Hér.) each contain more than 700 tree species (Beech et al., 2017), and Orchidaceae, one of the largest and most widespread flowering plant families, contains roughly 28,000 species (Fay, 2018). Additionally, clear assessments of species extinction risk (e.g., as published in the IUCN Red List of Threatened Species) are often lacking, as they require information about the range, which can be difficult to obtain when identifying rare taxa. Likewise, the long generation time in longer-lived individuals, such as trees, can make it difficult to prove population decline or recovery (Grace et al., 2021).

There is an urgent need to accelerate conservation action for the world's plants, and collaborative approaches are vital to this endeavor. Several existing frameworks provide a foundation for collective approaches, including the Specialist Groups (SGs) of the IUCN Species Survival Commission (SSC). These groups have nucleated around both plants and animals, and most have either taxonomically or geographically aligned foci. The fundamental objective of the SGs is to create networks of expertise that can enhance scientific understanding of imperiled organisms and their associated threats, and then effectively disseminate this information to action agents. These networks have been remarkably effective at consolidating previously disparate pools of information, filling knowledge gaps, and executing comprehensive IUCN Red List assessments of priority taxa. Reflective of the conservation resource imbalance highlighted above, however, there are currently 31 plant-focused SGs, which is a fraction of those that have formed to foster animal conservation. At present, there are 80 groups with a vertebrate focus, of which 36 are mammalian (IUCN Species Survival Commission, 2024). This is despite the fact that these groups comprise far less species diversity; based on recent estimates, plant species outnumber vertebrates 8:1 and mammals by almost 60:1 (Connor et al., 2018; Darimont et al., 2023; World Flora Online, 2024).

The accomplishments of the plant-focused SGs are nonetheless significant, with thousands of conservation assessments now collectively published and/or updated within the IUCN Red List. These accomplishments fuel conservation planning—an output of some but not all SGs—and set the stage for effective conservation action. "Action" is not, however, generally the purview of SGs, and the need for "action arms" has been acknowledged (Gregory and Lopez-Gallego, 2018). Past SG initiatives have created resources to aid organizations in starting and expanding plant conservation programs while sharing knowledge between institutions, such as the Global Trees Campaign (GTC), a collaboration between Botanic Gardens Conservation International (BGCI) and Fauna & Flora International (FFI) (e.g., Brewer, 2013 and other guidance briefs).

In parallel, a growing number of conservation action networks have been established on both national and regional scales, such as the Center for Plant Conservation, the Australian Network for Plant Conservation, Laukahi (the Hawai'i Plant Conservation Network), and the Custodians of Rare and Endangered Wildflowers program in South Africa. Other networks explicitly focus on ex situ conservation; examples include the American Public Gardens Association's Plant Collections Network (PCN) and the California Plant Rescue (CaPR). The PCN bridges institutions with common collection priorities, promotes excellence in plant collections management, and fosters exchange of rare and endangered plant material for collection back-up purposes. The CaPR initiative has been instrumental in rapidly accelerating ex situ capture of California rare plants (primarily through seed banking) on a specific regional level and is a model now being adopted in other regions. A limitation of many of these frameworks is that they are primarily volunteer driven, as volunteer-based initiatives can be challenging to sustain and vulnerable to personnel changes or shifts in institutional mandate.

SCALING UP COORDINATED CONSERVATION ACTION FOR PLANTS: GLOBAL CONSERVATION CONSORTIA

Despite the current growth in plant conservation networks, there remains a critical need to create additional conduits for collaborative conservation across regions and taxa. Here, we describe a new approach, the Global Conservation Consortia (GCC), initiated by BGCI in 2018 to scale up coordinated conservation action for highly threatened plant groups. The overall aim was to facilitate achievement of Target 8 of the Global Strategy for Plant Conservation that at least 75% of threatened plants be maintained in ex situ collections, preferably in the country of origin, with at least 20% available for recovery and restoration programs (Convention on Biological Diversity, 2012). The initial focus was strategically placed on plants that are challenging to grow, manage (e.g., exceptional species with seeds that cannot be stored by conventional means), and are found in biodiversity hotspots. Trees were also a priority for BGCI and many botanic gardens, as 30% of tree species are threatened with extinction globally (BGCI, 2021); furthermore, trees often serve as keystone species within ecosystems, making them valuable for conservation, and trees are also organisms with long generation times that require specialized and sustained conservation attention. An early natural starting point for the establishment of GCC was with plant groups that are already prioritized in the botanic garden sector, including charismatic yet threatened genera, so that additional support can be leveraged to expand and further establish world-class research and conservation programs. Existing interest and capacity by botanic garden partners has frequently led to the initiation of a GCC if they are able to provide justification for focus on the plant group and demonstrate sustained commitment to developing a GCC. Priorities for establishing additional GCCs in the future are currently being identified

by BGCI and partners, and take an inclusive approach to conserving threatened species in the most biodiverse regions of the world. Individuals and organizations interested in establishing or joining GCC are invited to contact BGCI.

This review focuses on three tree-focused, U.S.-led consortia: cycad, *Magnolia* L., and oak. However, a recent paper by Pirie et al. (2022) describes some of the opportunities and challenges for consortia in other parts of the world (particularly South Africa) and in including non-tree species. We describe how we have organized these consortia, provide examples of activities, and share insights on successes and challenges so far, as we "fine-tune" this new and exciting conservation approach.

DISCUSSION

The mission of the GCC program is to catalyze groups of institutions and experts to collaboratively develop and implement comprehensive strategies to prevent extinction of priority threatened plant groups (BGCI, 2024). As of January 2024, 11 consortia have been established, working to address the conservation needs for threatened taxa in *Acer* L., conifers, cycads, dipterocarps, Ebenaceae, *Erica* L., *Magnolia*, *Nothofagus* Blume, oak, *Rhododendron* L., and whitebeams, rowans, and service trees (BGCI, 2024). Each consortium has an appointed lead institution with a coordinator role assigned to one staff person; this coordinator works to track and catalyze efforts across their respective target plant group, and operates within a framework including a shared organizational structure comprising Consortium Leads and Coordinators, Steering Committees, Species Stewards, and Affiliates (Figure 2), as well as a set of objectives to address the conservation needs of these threatened plant groups (Box 1).

The unique value of the GCC program includes a global-to-regional, multi-sector species stewardship model to engage and include a variety of stakeholders for the regions and species that need the most help. In their functioning, the GCC have adopted the components of BGCI's Tree Conservation Programme framework: Prioritize, Plan, Act, and Monitor, with a foundation to empower, mobilize, and collaborate (BGCI, 2023a; Figure 3). Examples of how the GCC are implementing this framework through collaboration, both as a whole and specifically for cycad, oak, and *Magnolia*, are presented here in case studies.

Foundations: Empower, mobilize, collaborate

With an estimated 40% of the world's plants threatened with extinction, the ultimate goal for the development of the GCC and other networks is to scale up plant conservation action to meet current challenges (Antonelli et al., 2020). Fostering a supportive, adaptive, and sustainable community of conservation practitioners requires additional essential ingredients, including funding, expertise, and the ability to communicate and share information.

GCC grants

The GCC program is structured such that BGCI and each GCC will support and collaboratively fundraise when possible to meet GCC goals. Species conservation action via Species Stewards is naturally a high priority recognized by GCC. Through two new partnerships with the United States National Arboretum and the Bedgebury National Pinetum, BGCI launched the first annual GCC grant award in 2023, developed with the aim of directly supporting on-the-ground species conservation action. These small grants are available to existing GCC Species Stewards or to institutions that commit to becoming GCC Species Stewards as facilitated by a GCC grant-funded project. Projects should be focused on priority species of conservation concern for the relevant GCC, appropriate for a given species' conservation needs, compatible with previous efforts, and completed within one year. The goal is for this grant program to continue to grow and provide critical momentum for establishing long-term species conservation programs and dynamically managed metacollections, which are collections shared and with data managed across multiple institutions for research and conservation purposes.

Networking and training

The GCC Leads and Coordinators facilitate communications within each consortium through emails, newsletters, social media, the GCC website, and virtual as well as in-person meetings. These various platforms allow news on consortia resource documents, training and funding opportunities, project updates, and species-specific activities to be shared across the range of partners. Effective communication across multiple languages and cultures remains a challenge for the consortia at a global level; however, the use of simultaneous translation during virtual meetings and translation of key GCC documents have recently been successful at providing guidance to and engaging non-English-speaking partners in the consortia. The GCC have been developing and sharing online and in-person training on topics including species identification, propagation, and collection management. A Species Stewardship training course developed by The Morton Arboretum provides modules on the identification, collection, propagation, and planting of oak and other tree species, providing GCC partners with the tools, resources, and knowledge to develop and manage living conservation collections for threatened tree taxa in the long term.

Data sharing

Sharing information about plants in situ and ex situ is central to dynamic metacollections management, and a main objective of the GCC. Sharing and aligning collection provenance information between institutions

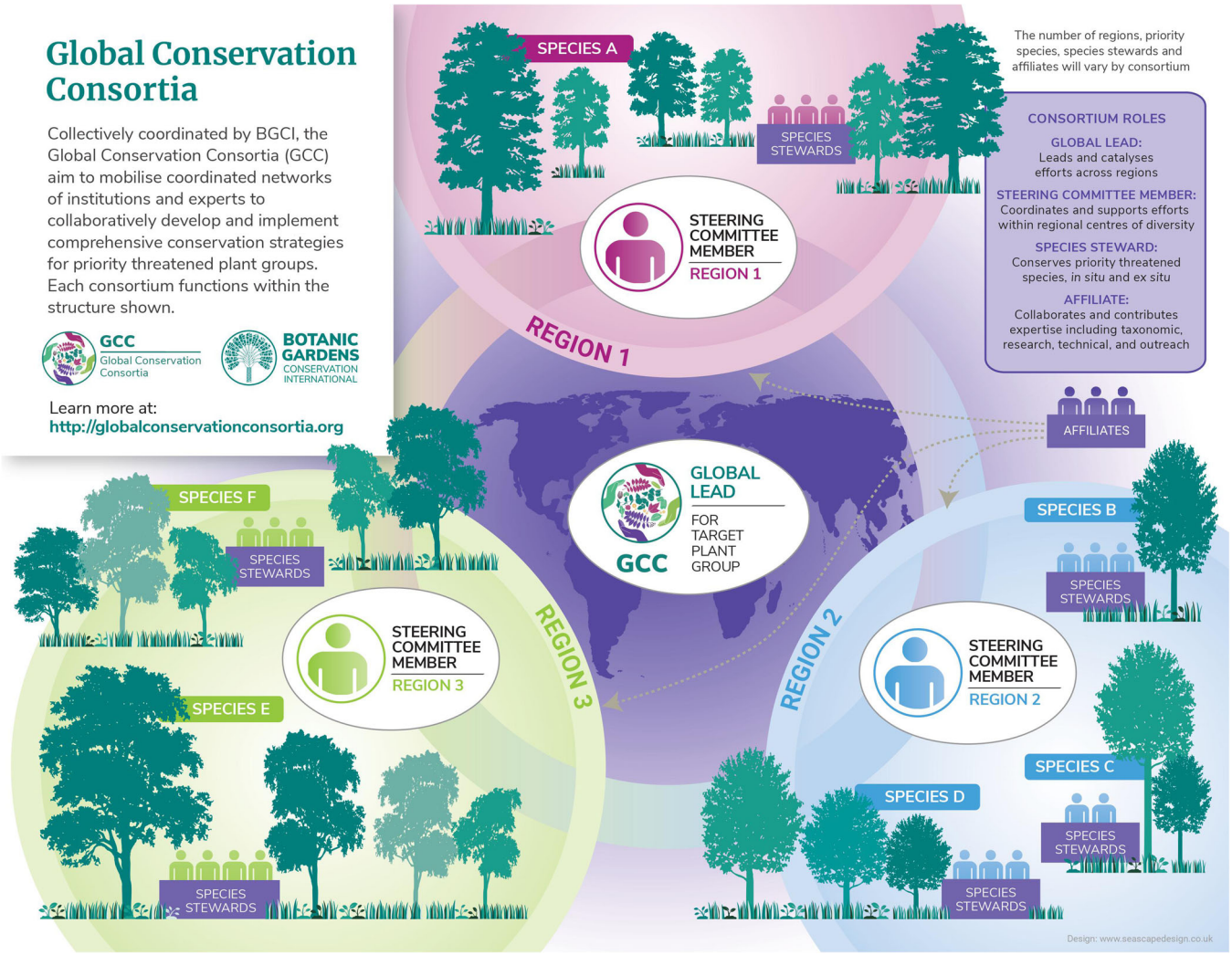

FIGURE 2 Structure and roles within Botanic Gardens Conservation International's Global Conservation Consortia. Image used courtesy of BGCI. Design: seascapedesign.co.uk.

is critical for conservation gap analysis and determining wild collecting priorities. BGCI's PlantSearch tool is the only global database of plants, seeds, and tissues maintained in botanic gardens and similar organizations around the world. It allows researchers, educators, students, conservation practitioners, and similar experts to identify collections of interest to support their work. The new PlantSearch Pedigree functionality allows for sharing of accession- and plant-level information to network collections working on the same species, and also supports gap analysis and metacollection management decisions. PlantSearch has recently been relaunched by BGCI, along with the new GardenSearch tool, with the central aims of sharing ex situ collections data and connecting living collections to the global botanical research and conservation community. The GCC have been providing accession data for the PlantSearch Pedigree tool and will continue to use this valuable resource in the development of comprehensive species conservation strategies.

Prioritize

Gathering data and identifying the species most in need of conservation, as well as defining the actions to take within the focal GCC, are the first steps in developing conservation strategies. Cycads, oaks, and magnolias are diverse, with over 300 species in each group. A systematic method to identify the most threatened species, as well as the conservation actions needed and potential collaborations, allows the GCC to allocate attention and resources efficiently and effectively. In situ data collection and monitoring of wild population trends guide conservation prioritization through time. The GCC are prioritizing species actions through the two-fold analyses of conservation assessment to identify extinction risk, and conservation gap analysis methodologies to assess gaps and provide recommendations for both ex situ and in situ actions.

As networks operating at both global and regional scales, the GCC aim to engage with a number of conservation assessment prioritization frameworks that

BOX 1. The programmatic objectives of the Global Conservation Consortia.

- Foster new and existing network(s) of experts
- Identify species of greatest conservation concern and prioritize conservation action
- Ensure effective in situ species conservation
- Establish, expand, and manage ex situ collections of high conservation value
- Foster applied research (e.g., conservation biology, ecology, horticulture, population genetics, taxonomy) to support species conservation
- Build capacity to empower and mobilize in-country partners in diversity centers and across species' ranges
- Increase public awareness and engagement with species conservation issues
- Collaboratively fundraise to scale up conservation action

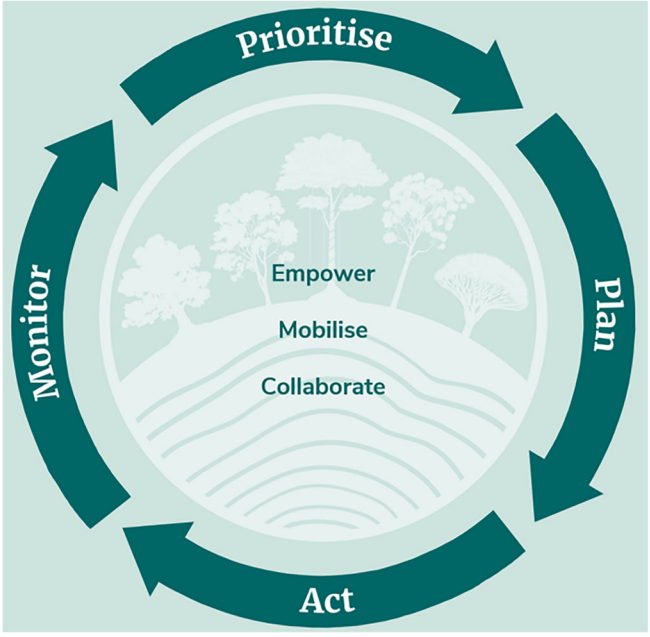

FIGURE 3 The Botanic Gardens Conservation International's integrated approach to the conservation and management of tree species.

will impact conservation. This includes both global frameworks such as the IUCN Red List of Threatened Species and regional organizations like NatureServe, an interdisciplinary group of conservation professionals focused on the United States and Canada. The focus of the Global Tree Assessment to engage experts through training and workshops to both update old and produce new global species assessments has led to publications guiding the GCC, including the Red List of Oaks 2020 (Carrero et al., 2020) and the Red List of Magnoliaceae (Rivers et al., 2016). In tandem, the IUCN Cycad SG, with support from GCC for Cycads members, recently completed a comprehensive reassessment of threat status of the world's cycads. These IUCN Red List assessments, completed in 2020 and published in 2022, serve as a critical update to the previous comprehensive assessment of cycads in 2009. These publications establish baselines of the state of each group globally and identify trends in threats and hotspots of diversity. The standardized methodology of the IUCN Red List allows comparison between species, and comprehensive assessment can lead to prioritization at the national, regional, and global levels (e.g., Jerome et al., 2017). The comprehensive gathering of information and analysis can also identify where threat and other important information about a species are lacking, leading to the designation of Data Deficient species and a recognition of the need for fundamental work in literature review, herbarium voucher study, and field surveys. In working with the NatureServe network, the GCCs are contributing to prioritization at a local level. For example, the GCC for Oak (GCCO) is providing NatureServe with information to identify priority populations for oak species of conservation concern in the United States. This information can be used in updating the NatureServe Conservation Status Assessment rank, which is frequently used in prioritization of conservation action at the federal, state, and provincial scales (NatureServe, 2024).

The information gathered to produce IUCN Red List assessments and NatureServe Conservation Status Assessments has been a basis for further conservation gap analysis methodologies used by the GCC and others. These methodologies, spearheaded by The Morton Arboretum and BGCI-US, engage conservation stakeholders in gathering and assessing information about target plant taxa including ex situ status, vulnerability of wild populations, and current as well as needed conservation actions. The standardized methodology for the flexible application of a conservation gap analysis includes steps of scope refinement, literature review and surveys, spatial analysis and mapping, and final analysis and reporting (Bruns, 2023). These methodologies both encourage and require early, frequent, and wide-ranging stakeholder involvement to ensure the analysis will be useful for planning and implementing future conservation strategies. Gap analyses have been published using these methodologies at the global level (e.g., the Global Conservation Gap Analysis of *Magnolia*; Linsky et al., 2022) and at the national level (e.g., the Conservation Gap Analysis of Native U.S. Oaks; Beckman et al., 2019). The native U.S. oaks and global *Magnolia* gap analyses employed a process of identifying species of conservation concern using a variety of the following metrics: IUCN Red List assessment category, NatureServe status ranking, vulnerability to climate change, and ex situ representation. The oak analysis identified 28 species of concern as a starting point for conservation of U.S. native oaks, and the *Magnolia* analysis identified 93 species of global priority.

Plan

Following research and the gathering of baseline information on species ecology, distribution, and threat status, as well as the identification of priority taxa, planning for conservation action can take place. The GCC have been actively working to develop species conservation action plans through the leadership of Consortium Leads and Coordinators. The conservation action plans help to address, prioritize, and mitigate the present and future challenges and threats for a species. In doing this, Coordinators have been trained as workshop facilitators, following the IUCN Conservation Planning Specialist Group (CPSG) Principles and Steps (a document that outlines eight practical steps for effective species conservation planning) process design and facilitation (CPSG, 2020). With this training, GCC Coordinators have since hosted numerous conservation action planning workshops to develop specific, achievable, and time-bound action plans that will be implemented to conserve species in the long term.

Via such workshops, the GCCO has developed conservation action plans for threatened oaks in the southeastern United States, California, and in Baja California, Mexico (GCCO, 2022a, 2022b). These plans outline each species' natural history, habitat, distribution, threats, current conservation efforts, interventions to mitigate threats, and the best next steps or activities to take for each species. During the implementation of the plan, stakeholders will meet on a quarterly and/or annual basis to coordinate, update the action plan, and share progress made with relevant stakeholders. Overall, the conservation action plans act as guiding documents for those who are working on, want to work on, or want to support conservation and research efforts for the focal species.

GCC for *Magnolia* Species Stewards at the Botanic Garden of Smith College and the United States National Arboretum have spearheaded efforts with support from the Consortium Lead and Coordinator to develop action plans for two native U.S. *Magnolia* species, *Magnolia fraseri* Walter and *Magnolia ashei* Weath., following their identification as species of concern based on range shifts and impacts from natural disasters, respectively. These plans have been developed over a series of in-person and virtual meetings, and contain multiple objectives geared toward understanding species status and trends in the wild, maintaining high value ex situ conservation collections, and promoting advocacy and awareness for *Magnolia* conservation. These plans will act as guides to the stewardship groups for these species over the coming years, and will also act as examples for conservation planning for other magnolias globally.

When the GCC for Cycads (GCCC) was launched, its Steering Committee identified southern Africa as a priority for network development given both the large number of endemic cycads and their state of imperilment. A GCCC Africa node was formed in 2023, via a Cycad Conservation Action Workshop held in South Africa. The focus of the workshop was action prioritization, accompanied by development of regional plans. In addition, Species Stewards recruited during this meeting are now spearheading interventions for 13 southern African species of *Encephalartos* Lehm. Concrete recovery plans are also being developed for 19 species currently assessed as Extinct in the Wild, Critically Endangered, or Endangered on the IUCN Red List. Following the model of this successful workshop, additional stakeholder forums will be convened across centers of cycad diversity. These regional efforts will be guided by an umbrella action strategy for cycads, called Cycads 2050 (IUCN Cycad Specialist Group, in press). This comprehensive global strategy was drafted by members of the IUCN Cycad Specialist Group (CSG) with support from the GCCC Steering Committee. It was vetted and formally adopted by the CSG in August 2023.

Act

The species conservation plans developed by the consortia lay out the steps for practical conservation actions to address the threats faced by each species. For some of the consortia, taxa are large and long lived, so space and capacity are two challenging factors in effectively growing and conserving the threatened species ex situ. Thus, one of the primary actions promoted by the GCC is the sharing of plant material and data in metacollections. Additionally, integrating in situ and ex situ strategies is a priority for the GCC where individuals held in ex situ collections may be used for research purposes such as common garden experiments, genetic diversity studies, selective breeding, and phenological studies, as well as to provide restoration/reforestation source material and opportunities for public education and outreach. A broad range of stakeholders have come together on GCC activities. The GCC have been engaging botanic gardens, universities, municipalities, government-managed lands, private landowners, tribal lands, provenance trial sites, living gene banks/repositories, and seed orchards to initiate collections and collaborate on ensuring that species are secure in the wild and in ex situ collections.

Partnerships for oak conservation

The GCCO has been piloting the metacollection partnership program—connecting partners from a variety of sectors to work together in order to develop genetically diverse conservation groves of long-lived oak species. The consortium identifies candidate botanic gardens and arboreta who will collect and propagate the wild germplasm and then work with a host site of sufficient size to design and plan a conservation grove, and help to plant, monitor, and maintain the grove in the long term, as part of the species' metacollection. One example of this partnership is between the United States Forest Service (USFS) and the Donald E. Davis Arboretum in Auburn, Alabama, USA. The GCCO

Coordinator has facilitated a partnership between the USFS regional geneticist and the curator of the arboretum, who works to collect and grow the Critically Imperiled Alabama sandstone oak (*Quercus boyntonii* Beadle) (Nichols and Thompson, 2023). Given the limited space of the arboretum, the curator was interested in finding additional space to grow this Critically Imperiled oak and conserve a sufficient level of its genetic diversity. In making this partnership, a site with over 100 planted oaks, including *Quercus georgiana* M. A. Curtis, another threatened oak native to the United States, was established at Beech Creek Seed Orchard, a USFS Genetic Resource Management Area located in Murphy, North Carolina, USA. The conservation groves of both species will grow over time, making these some of the largest collection sites for these two threatened species. Survivorship and growth data will be collected from the sites to assess how well the species perform in this region, providing useful information for the continued conservation of these priority, threatened taxa (Figure 4).

Active cycad conservation

After decades of severe poaching, wild populations of multiple cycad species have declined to near or complete extirpation in the wild (functionally or formally Extinct in the Wild on the IUCN Red List). For these taxa, in situ conservation is no longer feasible and, until genuinely secure sites are identified for reintroduction efforts, species survival is completely contingent on ex situ approaches. Given longevity, dioecy, and pollinator loss, the creation of specialized metacollections known as "assurance colonies" is critical. The latter term is borrowed from animal conservation practice, and designates secure, carefully managed breeding groups (in zoos, preserves, etc.) that serve as a buffer against extinction. Similar to animal conservation programs, recovery programs for Extinct in the Wild and Critically Endangered cycads often hinge on long-term reintroduction efforts, and assurance colonies are a pivotal resource in such endeavors. As with metacollections, assurance colonies are set up to be genetically representative, which presents a special challenge for many Extinct in the Wild and Critically Endangered cycads. Given the history—and ongoing threat—of poaching for the illegal plant trade, many cycad populations have been decimated or even extirpated by poachers. Hence, rare and coveted species may be well represented in private collections but virtually absent from curated conservation collections. This compounds the challenge of establishing genetically representative assurance colonies, as strategies must be developed for integrating privately held germplasm that was not legally procured and lacks provenance information. The latter contributes to misidentification and necessitates robust genetic assessment to determine levels of genetic diversity, genetic management units, clonal material, and cryptic species/hybrids. Currently, assurance colonies are being developed for multiple *Encephalartos* species in South Africa, Zimbabwe, and the United States and for at least one species of *Cycas* L. This work is complemented by genetic analysis underway within several research groups in the GCCC network (Handley and Nagalingum, 2018; Clugston et al., 2022).

Magnolia research and metacollections

Conservation planning for *Magnolia ashei* is guiding action including research and development of a genetically diverse and representative metacollection. Questions about reproductive patterns and variation across the range of the species and any impact on population trends are being addressed through seed collection and experimental germination by the United States National Arboretum. This research will help identify particular subpopulations that may be less reproductively successful and more in need of ex situ conservation actions, and will also provide information about the general population trend of the species. Simultaneously, the United States National Arboretum has made seed collections from across the range of the species with a plan to distribute seedlings to multiple gardens across the country as a metacollection. Collaborative management of this metacollection, including backup of individuals or even deaccessioning where over-representation occurs and resources are limited, will be informed by the wild population research and data sharing among the metacollection participants. These activities will aim to (a) develop comprehensive understanding of population trends to inform management and future conservation efforts and (b) ensure existing wild genetic diversity is conserved within a metacollection, thereby providing material for research, education, and (re)introduction.

Monitor

The framework of the GCC ensures monitoring is incorporated into all activities to assess progress and ensure that the aims and objectives of each consortium are being achieved. During meetings and as a part of data tracking, Species Stewards update species monitoring documents that gather data on stewards' activities ex situ (e.g., number of living collections of wild origin made and how representative the ex situ collection is of the wild population), in situ (e.g., is there active management and protection of the species in the wild), in public awareness (e.g., the types of awareness activities and numbers of people reached), as well as research (e.g., progress and outcomes of studies including genetics, ecology, or taxonomy). These documents act as a repository for different collaborating institutions to share information and refer to as new plans are made. These documents are used internally within Species Steward groups, and the consortia annually contribute these data to the Conservation Action Tracker (Quintana et al., 2024) within the

FIGURE 4 Creation of oak conservation groves. (A) A seedling of *Quercus acerifolia* (E. J. Palmer) Stoynoff & W. J. Hess is part of a metacollection in Columbia, Missouri, USA. (B) A conservation grove of *Q. engelmannii* Greene at Oak Glen Preserve in Yucaipa, California, USA. (C) The United States Forest Service has created a conservation grove of *Q. boyntonii* and *Q. georgiana* at Beech Creek Seed Orchard in Murphy, North Carolina, USA.

GlobalTree Portal (BGCI, 2023b) to more widely monitor and make public information about tree conservation action. The GCC Steering Committee members have developed work plans that allow for the monitoring of consortium goals as a whole. Species-specific projects carried out by the consortia also include monitoring to ensure project outputs are being completed. Annual reports of the consortia provide summaries of activities undertaken to advance the work plan objectives and are made available through GCC online channels.

CONCLUSIONS

The GCC for cycad, oak, and *Magnolia* have employed the organizational framework to begin to address objectives for taxa in each group, using data to prioritize species of greatest conservation concern, plan and implement action, and monitor activities on a number of levels. The consortia are benefiting from increasing momentum and expanding capacity, allowing them to develop comprehensive conservation action plans for priority species, create and expand high conservation value metacollections, and ensure the collections are used to support the persistence of species in the wild. The GCC initiative provides a strong framework and clear pathways to collaboration across sectors for plant conservation. The initiative will continue to grow through the expansion of current consortia and launching of new consortia for a variety of plant groups. The integration of conservation components including in situ, ex situ, horticulture, research, and education is made possible through collaboration, as the consortia progress from prioritization and planning to action and monitoring of plant conservation.

AUTHOR CONTRIBUTIONS

All authors conceived of this review. S.A.-C. created the outline of the manuscript. J.L. led the writing of the manuscript with contributions from all authors. J.L, A.B., and V.H. wrote the case study examples. All authors reviewed, edited, and approved the final manuscript.

ACKNOWLEDGMENTS

The authors thank our partners in conservation around the world who are collaborating as Steering Committee members, Species Stewards, and Affiliates of the Global Conservation Consortia (GCC), as well as data contributors. Without your tireless work, the GCC would not exist. We also thank Botanic Gardens Conservation International for providing leadership for the GCC program. This work was made possible in part by the Institute of Museum and Library Services (MG-245575-OMS-20), the United States Botanic Garden, and the United States Forest Service.

DATA AVAILABILITY STATEMENT

All supporting data are available with the published article.

ORCID

Jean Linsky http://orcid.org/0000-0002-3657-9283

REFERENCES

Adamo, M., R. Sousa, S. Wipf, R. A. Correia, A. Lumia, M. Mucciarelli, and S. Mammola. 2022. Dimension and impact of biases in funding for species and habitat conservation. *Biological Conservation* 272: 109636.

Antonelli, A., C. Fry, R. J. Smith, M. S. J. Simmonds, P. J. Kersey, H. W. Pritchard, M. S. Abbo, et al. 2020. State of the World's Plants and Fungi 2020. Royal Botanic Gardens, Kew, Richmond, United Kingdom.

Beckman, E., A. Meyer, A. Denvir, D. Gill, G. Man, D. Pivorunas, K. Shaw, and M. Westwood. 2019. Conservation Gap Analysis of Native U.S. Oaks. The Morton Arboretum, Lisle, Illinois, USA.

Beech, E., M. Rivers, S. Oldfield, and P. P. Smith. 2017. GlobalTreeSearch: The first complete global database of tree species and country distributions. *Journal of Sustainable Forestry* 36(5): 454–489.

Beech, E., M. Rivers, S. Andriambololonera, F. Lantoarisoa, H. Ralimanana, S. Rakotoarisoa, A. V. Ramarosandratana, et al. 2020. Red List of Dry Forest Trees of Madagascar. Botanic Gardens Conservation International, Richmond, United Kingdom.

BGCI. 2021. State of the World's Trees. Royal Botanic Gardens, Kew, Richmond, United Kingdom.

BGCI. 2023a. BGCI's Tree Conservation Programme [online]. Website: https://www.bgci.org/our-work/networks/bgcis-tree-conservation-programme/ [accessed 11 October 2023].

BGCI. 2023b. GlobalTree Portal [online]. Botanic Gardens Conservation International, Richmond, United Kingdom. Website: https://www.bgci.org/resources/bgci-databases/globaltree-portal/ [accessed 8 October 2023].

BGCI. 2024. Global Conservation Consortia [online]. Website: https://www.bgci.org/our-work/networks/global-conservation-consortia-gcc/ [accessed 18 January 2024].

Brewer, S. 2013. How to survey an area for threatened tree species. Global Trees Campaign. Fauna & Flora International, Cambridge, United Kingdom.

Bruns, E. B. 2023. Conservation Gap Analysis Methodology User Guide, Version 1.0. The Morton Arboretum, Lisle, Illinois, USA. Available at: https://mortonarb.org/gap-analysis-materials/ [accessed 17 April 2024].

Carrero, C., D. Jerome, E. Beckman, A. Byrne, A. J. Coombes, M. Deng, A. González-Rodríguez, et al. 2020. The Red List of Oaks 2020. The Morton Arboretum, Lisle, Illinois, USA.

Clugston, J., M. Ruhsam, G. Kenicer, M. Henwood, R. Milne, and N. Nagalingum. 2022. Conservation genomics of an Australian cycad *Cycas calcicola*, and the absence of key genotypes in botanic gardens. *Conservation Genetics* 23: 449–465.

Connor, J. B., J. P. Colella, P. L. Kahn, and N. S. Upham. 2018. How many species of mammals are there? *Journal of Mammalogy* 99: 1–14.

Convention on Biological Diversity. 2012. Global Strategy for Plant Conservation: 2011–2020. Botanic Gardens Conservation International, Richmond, United Kingdom.

CPSG. 2020. Species Conservation Planning Principles and Steps, Ver. 1.0. IUCN SSC Conservation Planning Specialist Group, Apple Valley, Minnesota, USA.

Darimont, C. T., R. Cooke, M. L. Bourbonnais, H. M. Bryan, S. M. Carlson, J. A. Estes, M. Galetti, et al. 2023. Humanity's diverse predatory niche and its ecological consequences. *Communications Biology* 6: 609.

Fay, M. F. 2018. Orchid conservation: How can we meet the challenges in the twenty-first century? *Botanical Studies* 59: 16.

GCCO (Global Conservation Consortium for Oak). 2022a. Oaks of the Californias' Conservation Action Plan [online]. Website: https://app.sheepcrm.com/bgci/gcc/gcc-oak/fa8862244a-oaks-of-the-californias-conservation-action-plan/ [accessed 23 August 2023].

GCCO (Global Conservation Consortium for Oak). 2022b. *Quercus boyntonii* Conservation Planning [online]. Website: https://app.sheepcrm.com/bgci/technical/gcc/news/Quercus-boyntonii-Conservation-Planning/ [accessed 25 August 2023].

Gordon, E. R., N. Butt, H. Rosner-Katz, A. D. Binley, and J. R. Bennett. 2020. Relative costs of conserving threatened species across taxonomic groups. *Conservation Biology* 34: 276–281.

Grace, M. K., H. R. Akçakaya, E. L. Bennett, T. M. Brooks, A. Heath, S. Hedges, C. Hilton-Taylor, et al. 2021. Testing a global standard for quantifying species recovery and assessing conservation impact. *Conservation Biology* 35: 1833–1849.

Gregory, T., and C. Lopez-Gallego. 2018. No more cycad extinctions: A line in the sand. *Cycads* 3: 4–5.

Griswold, E., S. Still, and A. McNeil-Marshall. 2018. Scouting and collecting rare oaks in the Trans-Pecos for ex situ conservation. *International Oaks* 29: 125–142.

Handley, V., and N. Nagalingum. 2018. Conservation through collaboration: A pilot project with *Encephalartos hirsutus*. *Cycads* 3: 24–26.

IPBES. 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES Secretariat, Bonn, Germany.

IUCN. 2020. IUCN Red List of Threatened Species, Version 2020.3. Website: https://www.iucnredlist.org [accessed 31 December 2020].

IUCN. 2023. The IUCN Red List of Threatened Species, Version 2022-2. Website: https://www.iucnredlist.org [accessed 23 August 2023].

IUCN Cycad Specialist Group. In press. Cycads 2050. A new strategy and action plan for the IUCN Cycad Specialist Group. *Philippine Journal of Systematic Biology*.

IUCN Species Survival Commission. 2024. Species Survival Commission [online] Website: https://www.iucn.org/our-union/commissions/species-survival-commission [accessed 18 January 2024].

Jerome, D., E. Beckman, L. Kenny, K. Wenzell, C.-S. Kua, and M. Westwood. 2017. The Red List of US Oaks. The Morton Arboretum, Lisle, Illinois, USA.

Linsky, J., D. Crowley, E. Beckman Bruns, and E. E. D. Coffey. 2022. Global Conservation Gap Analysis of Magnolia. Atlanta Botanical Garden, Atlanta, Georgia, USA.

Marinho, L. C., and E. Beech. 2019. The Red List of Tovomita. Botanic Gardens Conservation International, Richmond, United Kingdom.

Mohamed bin Zayed Species Conservation Fund. 2023. Grants awarded [online]. Website: https://www.speciesconservation.org/case-studies-projects/grants-awarded [accessed 23 August 2023].

Myers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. B. da Fonseca, and J. Kent. 2000. Biodiversity hotspots for conservation priorities. *Nature* 403: 853–858. https://doi.org/10.1038/35002501

NatureServe. 2024. NatureServe - Conservation Status Assessment [online]. Website: https://www.natureserve.org/conservation-status-assessment [accessed 1 February 2024].

Negrón-Ortiz, V. 2014. Pattern of expenditures for plant conservation under the Endangered Species Act. *Biological Conservation* 171: 36–43.

Nichols, E., and P. Thompson. 2023. Alabamas' unique Dwarf Oak. Alabama Cooperative Extension System. Website: https://www.aces.edu/blog/topics/4h/alabamas-unique-dwarf-oak/ [accessed 17 April 2024].

Pirie, M. D., R. Blackhall-Miles, G. Bourke, D. Crowley, I. Ebrahim, F. Forest, M. Knaack, et al. 2022. Preventing species extinctions: A global conservation consortium for *Erica*. *Plants, People, Planet* 4(4): 335–344.

Quintana, I., M. Rivers, and K. Davies. 2024. Conservation Action Tracker: A tool to identify and monitor conservation actions for tree species. *Applications in Plant Sciences* 12(3): e11579.

Rivers, M., E. Beech, L. Murphy, and S. Oldfield. 2016. The Red List of Magnoliaceae - Revised and extended. Botanic Gardens Conservation International, Richmond, United Kingdom.

Stephens, T. 2023. The Kunming–Montreal Global Biodiversity Framework. *International Legal Materials* 62(5): 868–887.

Westwood, M., N. Cavender, A. Meyer, and P. Smith. 2020. Botanic garden solutions to the plant extinction crisis. *Plants, People, Planet* 3: 22–32.

World Flora Online. 2024. World Flora Online. Website: https://www.worldfloraonline.org/ [accessed 30 January 2024].

How to cite this article: Linsky, J., A. Byrne, V. Handley, E. E. D. Coffey, S. Alvarez-Clare, D. Crowley, and A. Meyer. 2024. Integrated plant conservation through the Global Conservation Consortia. *Applications in Plant Sciences* 12(3): e11586. https://doi.org/10.1002/aps3.11586