Conserving Biodiversity through Ecological Restoration: The Potential Contributions of Botanical Gardens and Arboreta

Authors: Miller, James S., Lowry, Porter P., Aronson, James, Blackmore, Steve, Havens, Kay, et al.

Source: Candollea, 71(1) : 91-98

Published By: The Conservatory and Botanical Garden of the City of Geneva (CJBG)

URL: https://doi.org/10.15553/c2016v711a11

Conserving biodiversity through ecological restoration: the potential contributions of botanical gardens and arboreta

James S. Miller, Porter P. Lowry II, James Aronson, Steve Blackmore, Kay Havens & Joyce Maschinski

Abstract

MILLER, J.S., P.P. LOWRY II, J. ARONSON, S. BLACKMORE, K. HAVENS & J. MASCHINSKI (2016). Conserving biodiversity through ecological restoration: the potential contributions of botanical gardens and arboreta. *Candollea* 71: 91-98. In English, English abstract. DOI: http://dx.doi.org/10.15553/c2016v711a11

In the face of ever-increasing destruction and degradation of ecosystems and landscapes worldwide, there is critical and growing need for ecological restoration to maintain both biodiversity and the quality and quantity of ecosystem services. The term holistic restoration has been used for efforts with these dual goals. Botanical gardens and arboreta often have the full range of skills and resources needed to accomplish ecological restoration, including the ability to identify the appropriate species composition of reference ecosystems, to plan and design succession strategies, to propagate and cultivate trees and other plants for successful reintroduction, to monitor the success of restoration, and to play an important role in education and capacity building and serve as advocates for ecological restoration as part of a new paradigm of sustainability.

Keywords

Biodiversity – Botanical gardens – Natural capital – Ecological restoration – Sustainability

JSM: Missouri Botanical Garden, P.O. Box 299, St. Louis, MO 63166, U.S.A. E-mail: **james.miller@mobot.org**

PPL: Missouri Botanical Garden, P.O. Box 299, St. Louis, MO 63166, U.S.A. and Institut de Systématique, Evolution et Biodiversité (UMR 7205 – CNRS MNHN UPMC EPHE), Muséum national d'Histoire naturelle, Sorbonne Universités, C.P. 39, rue Cuvier 57, 75231 Paris CEDEX 05, France.

JA: Missouri Botanical Garden, P.O. Box 299, St. Louis, MO 63166, U.S.A. and Centre d'Ecologie Fonctionnelle et Evolutive (UMR 5175, CEFE – Campus du CNRS), route de Mende 1919, 34293 Montpellier, France.

SB: Botanic Gardens Conservation International, Descanso House, 199 Kew Road, Richmond, Surrey, TW9 3BW, U.K.

KH: Chicago Botanic Garden, 1000 Lake Cook Road, Glencoe, IL 60022, U.S.A.

JM: Fairchild Tropical Botanic Garden, 10901 Old Cutler Rd., Miami, FL 33156, U.S.A.

Submitted on February 2, 2016. Accepted on March 9, 2016. First published online on March 31, 2016.

ISSN: 0373-2967 – Online ISSN: 2235-3658 – *Candollea* 71(1): 91-98 (2016)

Introduction

We are using our planet's resources faster than they can be replenished. Whether measured by loss of species, decline of ecosystem resilience, or reduction in the quality and quantity of ecological services delivered, more than half of the world's terrestrial, coastal, and aquatic ecosystems have been impaired or destroyed, with almost all of this impact occurring in the last 250 years (Balmford & Bond, 2005; Gibson et al., 2011). The World Resources Institute reports that of the 30% of land area covered by forests prior to the industrial revolution, only 15% remains intact, while 35% is fragmented, 20% degraded, and the remaining 30% has been cleared completely. Most degraded or fragmented forests no longer provide the full array of habitat for native plants and animals nor the full array of ecosystem services on which our economies depend (MEA, 2005). There is an obvious and pressing need to reverse these trends and restore ecosystem health and integrity. This can be accomplished through various kinds of restoration, but for the present paper, ecological restoration is used to mean multidimensional restoration that integrates the goals of restoring ecosystem services, preserving biodiversity, and recovering self-sustaining ecosystems. The term 'holistic restoration' was used by Pandey (2002) for restoration undertaken as a 'holistic' endeavor to address ecological degradation, biodiversity loss, and sustainability simultaneously (Clewell & Aronson, 2007). It also includes restoration conducted in a local cultural context and that uses local knowledge and skills to restore an ecosystem in its entirety to a state of wholeness (Clewell & Aronson, 2007). The loss of ecosystem wholeness impairs ecosystem functionality, resilience, and hence ecosystem services, and thus negatively impacts human livelihoods and well-being (UNCCD, 2012). For example, 50 years ago, in the high-rainfall regions in northeastern Madagascar, farmers were able to grow three crops of rice each year, but today watersheds have been heavily deforested and wet season rainfall runs off so rapidly that local farmers can barely grow a single crop per year. Restoration of just the watershed function could be achieved by a relatively simple reforestation project including one or a small number of tree species, but ecological restoration involving a much larger complement of native plant species would additionally help conserve plant diversity and restore habitat for native animals, as well as restoring a full complement of ecosystem services.

It is clear that we have passed the point where preserving the last remaining intact natural areas will provide sufficient habitat for plants and animals and deliver adequate ecosystem services. Along with rethinking our excessive use of limited and dwindling natural resources and improving the sustainability of our technologies, we must invest significantly in the restoration of damaged ecosystems. If we are seriously committed to both improving human well-being and maintaining biodiversity in our congested and increasingly impoverished world, a fundamental paradigm shift is needed towards sustainability and a new relationship between people and nature that fully integrates the fundamental importance of plants as the matrix for all other terrestrial species.

There is some good news: in more than a dozen countries, large-scale programs of ecological restoration are being implemented in recognition that this is a global priority (Aronson & Alexander, 2013). Such projects help rebuild our ecological infrastructure (Nesshöver et al., 2011) or "natural capital" (e.g. Costanza & Daly, 1992; Aronson et al., 2007) and guarantee our ecological "life insurance" (European Parliament, 2012), all of which are under growing pressure. In this review, we provide a vision for the contribution that can be made by botanical gardens, arboreta, and seed banks, which are uniquely positioned to support ecological restoration, defined as having the goal of re-creating a self-sustaining ecosystem with the composition and structure like those of an appropriate reference ecosystem. Botanical gardens and arboreta are not the only players with skills to accomplish ecological restoration, but we argue that they could collectively play an important and special role because of they have a concentration of the broad set of skills and resources that are needed.

There is wide recognition that ecological restoration can make an important contribution to improving our global future. A commitment to restoration is exemplified by five of the sixteen targets of the Global Strategy for Plant Conservation (GSPC) of the U.N. Convention on Biological Diversity (CBD, 2012). Target 4 of the GSPC aims to secure at least 15 per cent of impaired portions of each ecosystem type through more effective management and active ecological restoration (CBD, 2012; see also www.cbd.int/gspc/targets.shtml). Restoration is also implicitly called for in GSPC Target 7, which aims to conserve 75% of threatened plant species *in situ*, a goal that will be impossible to achieve without restoration of degraded lands. Target 8, "having 75 per cent of threatened plant species in "ex situ" collections, preferably in the country of origin, and at least 20 per cent available for recovery and restoration", is also a strong endorsement of the need for restoration. Furthermore, the need to train adequate people, base them in appropriate facilities, and insure institutional capacity for conservation, as called for in GSPC Targets 15 and 16, certainly encompasses restoration expertise.

Botanical gardens and arboreta have responded to the GSPC in numerous ways. Botanic Gardens Conservation International (BGCI), established in 1987 under the auspices of the International Union for the Conservation of Nature (IUCN) [www.bgci.org/index.php?id=3007], is ideally placed to catalyze the efforts of botanical gardens in the global transition to broad scale, ecological restoration. BGCI unites over 700 members and other partners from 118 countries committed to work together in a coordinated network to promote the understanding of plants and their conservation. In 2012, BGCI helped launch the Ecological Restoration Alliance (ERA) of Botanic Gardens [www.erabg.org] as part of a community response to the GSPC Targets [www.plants2020.net], where an online toolkit is provided, with specific pages devoted to each of the targets. The ERA continues to grow and network to support and participate in efforts to achieve ecological restoration in and around protected areas, in inner cities, and everywhere in between.

The role of botanical gardens in ecological restoration

Botanical gardens and arboreta are strongly positioned to contribute to addressing the challenge of restoring natural areas by serving as indispensable centers for the science and practice of ecological restoration (Aronson & The ERA of Botanic Gardens, 2014). Botanical gardens are dedicated to understanding, preserving and utilizing plant diversity in a variety of ecosystems. Gardens and arboreta have experienced scientists and horticulturalists with the knowledge and competence accrued over decades that are essential to carry out and support successful restoration work. These institutions typically have long-established research programs that document plant diversity and many have programs in plant ecology, conservation, and restoration. They are also centers of excellence for the horticultural skills necessary to propagate and successfully grow the species needed to restore terrestrial ecosystems. Moreover, they have staff with the ability to identify plant material accurately, an essential but often overlooked skill required for ecology and restoration. Furthermore, botanical gardens serve as repositories for documented plant material and associated information resources (collected specimens, books, journals, archival material, electronic databases, etc.), and collectively they maintain nearly one-third of the estimated 300,000 known flowering plant species in their combined living collections (Sharrock, 2012). Botanical gardens and arboreta also work beyond their walls to network, educate, advocate, develop policy, build capacity, and engage in restoration projects throughout the world.

Contributions botanical gardens can make to ecological restoration

Botanical gardens have evolved over the centuries from centers of learning about medicinal plants to collections of diverse and unusual plants and centers for the art and technology of gardening, to repositories of all kinds of plant diversity, not just that of interest as a curiosity. In recent years most gardens have made a strong commitment to conservation (Raven, 2004), embracing formal conservation efforts, and a growing number are now actively supporting ecological restoration. Many gardens have seed banks of both rare and common native species that are available as source material for restoration (Maunder et al., 2004). Modern gardens and arboreta have evolved into centers that conduct and facilitate rigorous research in plant and ecological science, house expertise in horticulture, and have made long-term commitments to conservation projects with significant outreach and educational components, all of which can further support and enhance restoration work.

Understanding historical diversity and reconstructing reference ecosystems

Expertise in systematics is essential for high quality ecological restoration, one of the key goals of which is to re-establish a complement of biological diversity similar to that found in a reference ecosystem, either one known or presumed to have been present prior to human disturbance, or with a species composition that might be expected to be adapted to local conditions. When ecosystems are highly degraded or completely destroyed, historical herbarium collections may be the only resource available to determine which species might have occurred in the now-degraded or lost ecosystem. The consultation of historical collections may therefore be an essential step toward reconstructing the species composition of forests that no longer exist, and without this record it might be impossible to restore the original complement of species.

For example, the Missouri Botanical Garden maintains a network of 12 community-based conservation sites in Madagascar. These projects integrate botanical inventory, identification of threatened species, and restoration efforts. One of them, situated on Madagascar's central plateau about 120 km north of the capital, Antananarivo, and just north of the town of Ankazobe, focuses on a small forest remnant known as Ankafobe. The remaining forest, which covers only 33 hectares but provides habitat for three species of lemurs, is situated along a small stream in a valley between two hills, and the humid nature of the resulting microhabitat likely contributed to its survival in the face of annual fires that burn the surrounding anthropogenic grassland, which is dominated by exotic species (Fig. 1A-B). While the Ankafobe forest is too small and degraded to have retained the full complement of the species that must have occupied the area when it was fully forested, a robust archival record of the area's flora is available in the form of historical herbarium specimens that serve as a reference for restoring botanical diversity and propagating material for restoration and enrichment planting. The Ankafobe project aims to restore enough forest to provide adequate habitat for the lemur species that have recently returned to the fragment and to expand the watershed so that sufficient water will be available to support agriculture in downstream areas, but the species composition of forest that originally covered the region can only be recreated by compiling information from historical collections.

Fig. 1. – Restoration in action. **A.** Remnant native forest being restored by protection, enrichment planting of native species, and the elimination of fire through using fire breaks; **B.** Firebreaks and controlled burning protect native forest from annual fires that burn throughout much of Madagascar's central plateau; **C.** Thicket vegetation with a monoculture of common buckthorn (*Rhamnus cathartica* L.), one of the region's worst invasive species; **D.** View of a section of McDonald Woods that has been restored by removing buckthorn, planting seedlings of native species, and returning the prescribed fire regime.
[**A-B:** Ankafobe forest, Madagascar, a restoration site run by the Missouri Botanical Garden; **C-D:** McDonald Woods, Chicago Botanical Garden, U.S.A.]
[Photos: **A:** J. Leighton Reid; **B:** C. Birkinshaw; **C-D:** J. Steffen]

Designing and planning restoration

Expertise in plant taxonomy and ecology found at botanical gardens and arboreta is useful not only for understanding the taxonomic composition and community structure of reference ecosystems, but also for designing and planning the controlled or assisted succession needed to re-establish natural communities. Ecologists working at these institutions are well suited to assess damaged sites and determine whether they are candidates for assisted recovery (which involves protection while natural regeneration occurs, often with the removal of non-native species) or whether they require complete restoration. For example, the Chicago Botanical Garden's efforts to restore its 40 hectare McDonald Woods required total removal of highly invasive common buckthorn (*Rhamnus cathartica* L.), which formed a nearly monospecific thicket (Fig. 1C), followed by controlled burning and seeding with native species to promote the return of oak woodland vegetation (Fig. 1D). Many sites in need of restoration are, however, degraded or destroyed beyond the point where they can serve as a nucleus for re-establishing a community comprising plant species present in a reference ecosystem. In these sites, soil analyses may also be required, and restoration design may need to address inadequacies in soil nutrients, organic matter, and/or aeration. For example, much of the native habitat in the western United States is degraded as a result of changes imposed by invasive species, altered fire regimes and land use patterns, and a shifting climate. For restoration to succeed in such highly degraded landscapes, it may be essential to design succession with early pioneer species that can compete with invasive species and tolerate harsh conditions. In collaboration with the Colorado Plateau Native Plant Program, the Chicago Botanical Garden has conducted greenhouse and field trials to identify native species and ecotypes that are good competitors with invasive species and tolerate disturbance (also known as "native winners"; Barak et al., 2015) since these may improve restoration outcomes on highly degraded sites. This research includes trials to understand seed ecology and patterns of local adaptation among populations of target study species, with the goal of informing restoration application and seed sourcing decisions. Much of the seed used in these trials has come from the national Seeds of Success (SOS) program, which aims to collect wildland native seed for research, development, germplasm conservation, and ecosystem restoration. SOS is led by the U.S. federal Bureau of Land Management in partnership with several gardens, including Chicago Botanical Garden (Haidet & Olwell, 2015). Many of the successful means of accomplishing restoration, particularly in early stages, may be the consequence of trial and error as well as casual experimentation, the best of which has been referred to as Intelligent Tinkering (Murcia & Aronson, 2014), but the key to fostering the growth of restoration science is designing studies as experiments that can test ecological theory (Falk et al., 2006). For example, the Atlantic Forest Restoration Pact aims to restore 15 million hectares of Brazilian Atlantic forest by 2050 (Rodriguez et al., 2009). This effort will carefully compare six different restoration methods using a common monitoring protocol and the results will provide compelling evidence for identifying the most effective approach in this region.

If biodiversity conservation is considered an integral goal of ecological restoration, then the capacity to include rare species in designed successions for restoration is essential. Botanical gardens have made great contributions in the specialized area of rare plant reintroductions. A recent review of work conducted since 1985 highlighted the role of botanical gardens affiliated with the Center for Plant Conservation, as well as progress made throughout the world. Reintroductions have also helped to reduce extinction risk of the rarest plant species in the world (Maschinski & Haskins, 2012).

Implementing restoration

Horticulture is at the heart of every public garden's mission and it is also a key component of successful restoration. Horticultural expertise is needed to gather appropriate seeds, maintain and/or store them long-term in seed banks, and germinate and grow them. Horticulturists and plant population geneticists have the skills and know-how to select appropriate plants and grow them so they perform well and have the best possible survival rate once planted in restoration sites. Successful implementation requires sufficient genetic diversity of locally adapted plants and efforts to ensure that restored landscapes can be successful arks for the preservation of rare plant species. Coordinated efforts are needed to develop the technology to achieve restoration on very large scales, and gardens are important players in these efforts.

Restoration also requires access to seeds of many species. Seed banks can supply material of the species needed to restore the basic structure and composition of a local ecosystem, including threatened plant species that are critical for conservation efforts (Guerrant et al., 2014). Many botanical gardens maintain seed banks and have conservation geneticists on staff with the skills to ensure that accessions have the appropriate genetic constitution to survive locally. The Greater Caucasus Seed Bank, maintained at the Botanical Institute of the Georgian Academy of Sciences, has the goal of collecting and banking seeds of the region's rare and threatened plant species, and producing plants for reintroduction at numerous sites to increase abundance of these species, thereby reducing their risk of extinction.

Plant material used in restoration should come from an area that is ecologically similar and preferably located nearby as plants of unknown or distant provenance may be less likely to survive or reproduce, although seed sourcing protocols may change as the climate changes (Havens et al., 2015). Botanical gardens increasingly employ conservation geneticists who can help ensure that appropriate plant material is obtained and used, and who can also help ensure that there is adequate genetic variability among the plants used to ensure healthy breeding, self-reproducing populations. Unless special care is taken, seed collection and propagation methods can fail to deliver the genetic variability essential to enable populations to respond to changing environmental conditions and selection pressures (Basey et al., 2015). The Chicago Botanical Garden has run trial surveys with *Cirsium pitcheri* (Torr. ex Eaton) Torr. & A. Gray in Illinois Beach State Park (Fant et al., 2013) and *Castilleja levisecta* Greenm. in western Oregon and Washington (Basey, pers. comm.) to determine whether genetic bottlenecks may be encountered in the reintroduction strategy being used and whether certain seed sources reproduce more favorably at the reintroduction sites.

While many of the ecological restoration projects being conducted by botanical gardens are relatively small-scale, they often have ambitious goals. Scaling up to restore the full complement of species from an original reference ecosystem in larger areas may require additional horticulture skills beyond those available at most botanical gardens. Scientists from the King's Park and Botanic Garden in Western Australia have developed new technologies they are now using to facilitate the germination and establishment of seeds in large-scale restoration efforts at mine sites (Dixon et al., 2009). The large size of most of these sites makes it impractical to use seedlings or young plants, and the conditions are often too harsh for on-site germination and establishment from seeds. The King's Park group and collaborators from local universities have been experimenting with encasing seeds in absorbent organic materials that help retain moisture in the immediate environment of the germinating seed and also provide necessary nutrients to support strong growth and establishment. They have also established a seed bank specifically for use in these restoration projects (Merritt & Dixon, 2011). In the U.S., botanical gardens partnering with the Bureau of Land Management are working on addressing the challenges of scaling up seed supplies for restoration in western states through Seeds of Success, a national seed collection and banking program (Havens et al., 2014).

Monitoring restoration

Plant ecologists and systematists are ideally suited to monitor restoration projects and track the development of populations, communities, and entire ecosystems. Similarly, conservation geneticists can help determine and track the genetic constitution of restored populations of plant species and determine whether it is comparable with that found in natural communities. These same skills, along with those of arborists and horticulturists, are necessary to facilitate and direct succession as well as seed dispersal and "in situ" germination and seedling establishment of native plants, many of which may never have been studied previously in a horticultural context. Because success is often measured by the amount of native biodiversity restored, systematists and ecologists have the expertise needed to conduct the biological inventories and ecological surveys that will provide a basis for determining whether a project is on target at each stage of implementation. Furthermore, horticulturists can gauge how well plants are growing and when problems are encountered, they can identify the factors that may be limiting growth and survival, and they can suggest how these issues can best be addressed. It is important to note, however, that restoration is much more than gardening at a large scale ; it requires a carefully integrated approach to re-constitute a self-sustaining ecosystem, which botanical gardens and arboreta are especially well suited to help deliver.

The goal of restoring original diversity will no doubt remain elusive in many contexts, especially in tropical areas. Major investments in improving the science and technology for achieving restoration in different vegetation types are urgently needed. Efforts to restore wetlands in temperate and cold regions, which are comparatively simple and species-poor ecosystems, have only achieved 70-80 % recovery of biodiversity and ecosystem functioning, on average, after five decades or more (Moreno-Mateos et al., 2012). For most other ecosystems in which restoration has been attempted, current success rates are lower. Yet botanical gardens have demonstrated long-germ commitments to various conservation projects that, even if they never achieve the full complement of species occurring in an original reference ecosystem, they may help move restored areas to a point where they are self-sustaining, with natural ecological interactions that over time may continue to evolve toward greater taxonomic and functional complexity. Botanical garden researchers can also contribute to monitoring the quality and quantity of ecosystem services provided by a restored area. Many restoration projects have been designed primarily for erosion control, protection of watersheds, and creation of suitable wildlife habitat, all of which can be measured with techniques used regularly by botanical gardens and their staff members.

Advancing and teaching restoration

Successful efforts to restore sufficiently large areas to protect biodiversity and/or restore ecosystem services will require teaching, capacity building, and strong advocacy. This is fully consistent with the mission of many botanical gardens and their education, training and outreach programs. These institutions are well equipped to teach both children and adults about realistic expectations for restoration projects, from large scale efforts designed to restore many hectares to smaller efforts that might be undertaken on private lands or in a city. Education targeting both professionals and the general public is necessary to promote ecological restoration and advance the understanding that restoration can encompass many possible strategies and can be beneficial in a wide range of situations.

For example, Fairchild Tropical Botanic Garden founded the Connect to Protect Network (CTPN), a corridor program that uses public outreach, education, and restoration support to help establish healthy native pine rockland corridors and stepping stone gardens on both public and private properties. Increasing the total number of native plant species in this globally endangered ecosystem may facilitate pollen and seed transfer across existing and newly created forest patches. Equally important is the opportunity to connect children, parents, teachers, and policy makers to the importance of preserving natural heritage within the urban matrix (Powell & Maschinski, 2012).

Botanical gardens can also harness their international programs to train and build capacity for conducting successful restoration work around the world. This is particularly important in tropical areas where species diversity is often very high, and especially in developing countries where local expertise and resources are limited. Given the skills and resources available in botanical gardens and arboreta, these institutions are well equipped to support ecological restoration to historically accurate or ecologically appropriate reference ecosystems.

Prospects for the future

There is a clear and urgent need for substantially expanding and improving ecological restoration to counter the degradation and destruction that has impacted a large and growing portion of the world's terrestrial ecosystems, and as we move further past the tipping point beyond which the quality and quantity of ecological services are no longer adequate and countless species are disappearing. Restoration will not be sufficient on its own. Sustainable agroforestry and civil engineering projects can help repair dysfunctional watersheds, although they rarely make a significant contribution to maintaining and conserving biodiversity. Botanical gardens and arboreta have the combined set of skills needed to restore a given landscape appropriately. As we move ahead, society needs to meet this challenge by making this the century of ecological restoration. Botanical gardens are doing their part by mobilizing and building new relationships with other sectors to make an important contribution to this critical effort.

The Ecological Restoration Alliance has taken root (Aronson & The ERA of Botanic Gardens, 2014). Botanical gardens and arboreta, along with similar institutions, are now positioned to make a significant contribution to the complex yet vital process of ensuring that restoration is fully integrated into efforts to transition our global society away from 'business as usual' towards a sustainable future. A greatly expanded set of exemplary restoration initiatives are needed at small, medium and large scales, and across all ecosystem types, everywhere on the planet.

Acknowledgements

We thank all participants in meetings convened by BGCI at the New York Botanical Garden (2012), Brackenhurst Conference Center, Kenya (2013), the Missouri Botanical Garden (2014), the Royal Botanic Garden, Amman, Jordan (2015), and the Royal Botanic Gardens, Edinburgh (2015), all of whom contributed to the ideas presented in this article. We also wish to thank several anonymous reviewers who provided valuable comments on an earlier version of the manuscript.

References

Aronson, J. & The ERA of Botanic Gardens (2014). The Ecological Restoration Alliance of botanic gardens: a new initiative takes root. *Restorat. Ecol.* 22: 713-715.

Aronson, J. & S. Alexander (2013). Ecosystem restoration is now a global priority: Time to roll up our sleeves. *Restorat. Ecol.* 21: 293-296.

Aronson, J., S.J. Milton & J.N. Blignaut (ed.) (2007). *Restoring natural capital: science, business and practice*. Island Press, Washington, DC.

Barak, R.S., J.B.Fant, A.T. Kramer & K.A. Skogen (2015). Assessing the value of potential "native winners" for restoration of cheatgrass-invaded habitat. *W. N. Amer. Naturalist.* 75: 58-69.

Basey, A.C., J.B. Fant & A.T. Kramer (2015). Producing native plant materials for restoration: 10 rules to collect and maintain genetic diversity. *Native Pl. J.* 16: 37-53.

Balmford, A. & W. Bond (2005). Trends in the state of nature and their implications for human well-being. *Ecol. Letters* 8: 1218-1234.

CBD [Convention on Biological Diversity] (2012). *UNEP/CBD/COP Decision XI/16. Ecosystem Restoration* [https://www.cbd.int/doc/decisions/cop-11/cop-11-dec-16-en.pdf].

Clewell, A.F. & J. Aronson (2013). *Ecological restoration: principles, values, and structure of an emerging profession.* 2nd ed. Island Press.

Costanza, R. & H. Daly (1992). Natural capital and sustainable development. *Conservation Biol.* 6: 37-46.

Dixon, K.W., D.J. Merritt, G.R. Flematti & E.L. Ghisalberti (2009). Karrikinolide – A phytoreactive compound derived from smoke with applications in horticulture, ecological restoration and agriculture. *Acta Hort.* 813: 155-170.

European Parliament (2012). *Our life insurance, our natural capital: An EU biodiversity strategy to 2020 (2011/2307 - INI)* [ec.europa.eu/environment/nature/biodiversity/comm2006/pdf/EP_resolution_april2012.pdf].

Falk, D., M. Palmer & J. Zedler (ed.) (2006). *Foundations of restoration ecology.* Island Press, Washington, DC.

Fant, J.B., A.T. Kramer, E. Sirkin & K. Havens (2013). Genetics of reintroduced populations of the narrowly endemic thistle, Cirsium pitcheri (Asteraceae). *Botany* 91: 301-308.

Gibson, L., T.M. Lee, L.P. Koh, B.W. Brook. T.A. Gardner, J. Barlow, C.A. Peres, C.J. Bradshaw, W.F. Laurance, T.E. Lovejoy & N.S. Sodhi (2011). Primary forests are irreplaceable for sustaining tropical biodiversity. *Nature* 478: 378-381.

Guerrant, E.O., K. Havens & P. Vitt (2014). Sampling for effective ex situ plant conservation. *Int. J. Pl. Sci.* 175: 11.20.

Haidet, M. & P. Olwell (2015). Seeds of Success: a national seed banking program working to achieve long-term conservation goals. *Nat. Areas J.* 35: 165-173.

Havens, K., A.T. Kramer & E.O. Guerrant (2014). Getting plant conservation right (or not): The case of the United States. *Int. J. Pl. Sci.* 175: 3-10.

Havens, K., P. Vitt, S. Still, A.T. Kramer, J.B. Fant & K. Schatz (2015). Seed sourcing for restoration in an era of climate change. *Nat. Areas J.* 35: 122-133.

MEA [Millennium Ecosystem Assessment] (2005). *Ecosystems and human well-being: general synthesis* [http://www.millenniumassessment.org/documents/document.356.aspx.pdf].

Maschinski, J. & K.E. Haskins (2012). *Plant reintroduction in a changing climate: promises and perils.* Island Press, Washington, DC.

Maunder, M., K. Havens, E.O. Guerrant & D. Falk (2004). Ex situ methods: A vital but underused set of conservation resources. *In:* Guerrant, E.O., K. Havens & M. Maunder (ed.), *Ex Situ plant conservation: supporting species survival in the wild:* 3-20. Island Press, Washington, DC.

Merritt, D.J. & K.W. Dixon (2011). Restoration seed banks – A matter of scale. *Science* 332: 424-425.

Moreno-Mateos, D., M.E. Power, F.A. Comín & R. Yockteng (2012). Structural and functional loss in restored wetland ecosystems. *PLoS Biol.* 10: e1001247.

Nesshöver, C., J. Aronson, J.N. Blignaut, D. Lehr, A. Vakrou & H. Wittmer (2011). Investing in ecological infrastructure. *In:* Ten Brink, P. (ed.), *The economics of ecosystems and biodiversity in national and international policy making:* 401-448. Earthscan, London & Washington, DC.

Pandey, D.N. (2002). Sustainability science for mine-spoil restoration. *Curr. Sci.* 83: 593-602.

Powell, D. & J. Maschinski (2012). Connecting fragments of the pine rockland ecosystem of South Florida: the connect to protect network. *Ecol. Restorat. N. Amer.* 30: 285-288.

Raven, P.H. (2004). Ex situ conservation. *Public Gard.* 19: 7.

Rodrigues, R.R., R.A. Lima, S. Gandolfi & A.G. Nave (2009). On the resoration of high diversity forests: 30 years of experience in the Brazilian Atlantic Forest. *Biol. Conservation* 142: 1242-1251.

Sharrock, S. (2012). *Global strategy for plant conservation – A guide to the GSPC. All the targets, objectives, and facts.* Botanic Gardens Conservation International, Kew [https://publicgardens.org/resources/guide-gspc-global-strategy-plant-conservation-all-targets-objectives-and-facts].

UNCCD [United Nations Convention on Combatting Desertification] (2012). *Zero Net Land Degradation, a Sustainable Development Goal for Rio+20* [www.unccd.int/Lists/SiteDocumentLibrary/Rio+20/UNCCD_PolicyBrief_ZeroNetLandDegradation.pdf].