

Botanic gardens should lead the way to create a “Garden Earth” in the Anthropocene

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ARTICLE INFO

Article history:

Received 15 May 2017

Received in revised form

10 November 2017

Accepted 13 November 2017

Available online 24 November 2017

(Editor: Vernon Heywood)

Keywords:

Green infrastructure

Botanic garden

Ex-situ conservation

In-situ conservation

Botanical garden

ABSTRACT

The strength and expertise that botanic gardens bring to conservation are based on their detailed knowledge and understanding of the care, management, and biology of a diversity of plant species. This emphasis on the organism has led to many *ex-situ* and *in-situ* conservation programs aimed at protecting endangered species, restoring threatened populations, and establishing living plant and seed collections of endangered species. In China, the scale and pace of change in land and resource use, often leading to environmental degradation, has created a strong emphasis on improving environmental conditions. If done properly, being “green” can be a surprisingly complex issue, because it should encompass and exploit the whole of plant diversity and function. Unfortunately, ‘green’ often includes a small portion of this whole. Earth’s rich plant diversity presents considerable opportunity but requires expertise and knowledge for stable and beneficial management. With the dawning of the Anthropocene, we should strive to live on a “Garden Earth”, where we design and manage our environments, both built and natural, to create a healthy, beneficial living landscape for people and other organisms. The staff of botanic gardens worldwide and the living collections they maintain embody the best examples of sustainable, beautiful, and beneficial environments that thrive on plant diversity. This expertise should be a fundamental resource for agencies in all sectors responsible for managing and designing “green” infrastructure. Botanic gardens should actively engage and contribute to these opportunities, from large public infrastructure projects to small private conservation efforts. Here, we discuss several ongoing conservation efforts, primarily in China, and attempt to identify areas where botanic gardens could make a significant and meaningful difference.

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Building on strengths of botanic gardens

The origin of the modern botanic garden was primarily the pursuit of “three things which have stimulated [humanity] throughout the ages to travel far and wide over the surface of the globe, and these are gold, spices and drugs” (Hill, 1915). Dr. Hill claims, in the next sentence, that only the latter two were major factors in the development of botanic gardens but his statement seems slightly disingenuous: wealth has certainly a major motivation as well. Kew Garden’s expertise and global reach was central to the British Commonwealth’s economy and development and their actions transformed cultures and natural landscapes. In this

way, botanic gardens have long been viewed as a ‘testing ground’ for potentially valuable plants and this experimentation does not come without risk (Dawson et al., 2008). During the 20th century in the West, through leading institutions like Kew Gardens, Missouri Botanic Gardens, and the Arnold Arboretum, both *in-situ* and *ex-situ* conservation programs have increasingly engaged scientific expertise and knowledge to improve and conserve our natural botanical wealth (Blackmore and Oldfield, 2017; Cavender et al., 2015; Chen et al., 2009; Smith, 2016).

China also has a long history of horticultural expertise. The wealth of botanical knowledge can be seen in many of its historical and existing traditional gardens. These gardens are deliberately designed to reflect the spirit of the larger landscape, sometimes via miniaturization of natural elements, such as using ornamental rocks to mimic mountain landscapes (Keswick and Hardie, 2003). Primarily for the personal pleasure of wealthy and powerful

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Peer review under responsibility of Editorial Office of Plant Diversity.

individuals, these classical gardens served as the expression of a refined and balanced lifestyle. Modern scientific gardens did not emerge in China until after World War II (Hu et al., 2015), when the Chinese Academy of Sciences (CAS) created numerous botanic gardens throughout the country with three main tasks: 1) exploiting and collecting wild plant resources, domestic and foreign, to enrich China and contribute to its development; 2) study and scientifically improve plant growth, adaptation, and economic value; and 3) create exhibits and experiments that integrate beauty and science to advance botanical knowledge and appreciation (Yu, 1983). While relatively few gardens, mostly part of CAS, have played a major role in botanical research and knowledge for over the past fifty years in China, the growth and investment into botanic gardens by municipalities and states prompted CAS and several Chinese ministries to create a Chinese Union of Botanical Gardens (CUBG) in 2013 to develop, train and promote their overall activities. These newer botanic gardens were founded to provide specific tangible benefits for society, like medicinal plant research, ornamental plant development and for public recreation.

Additionally, several large national and international associations have formed to bring together botanic gardens of all sizes and foci to better leverage and promote the overall mission of plant conservation, utilization, and appreciation. Fortunately, the emphasis on scientific research has remained at the forefront of these associations. Founded in 1954, the International Association of Botanic Gardens (IABG) is an international organisation that promotes international cooperation among botanic gardens, arboreta and similar institutes worldwide via scientific studies and conservation of plants (“International Association of Botanic Gardens,” n.d.). Established in 1987, Botanic Gardens Conservation International (BGCI), with more than 500 members from over 100 countries, is now the largest plant conservation organization in the world. The mission of BGCI is ‘to mobilise botanic gardens and engage partners in securing plant diversity for the wellbeing of people and the planet’ (“Mission and strategy,” n.d.). Similarly, the Chinese Union of Botanical Gardens (CUBG) unites almost 100 botanic gardens in China for the equitable development and distribution of technology, training and plant resources (“Chinese Union of Botanical Gardens,” 2017). Through the recent growth of large botanic garden networks, the powerful scientific knowledge pioneered by key leading botanic gardens can now be expanded and replicated more easily across the globe. The linking of individual botanic gardens certainly creates a stronger means of promoting and conducting botanical research. These networks can allow botanic gardens of all sizes and emphases, which are often locally oriented and tightly integrated into their surrounding communities, to contribute to large research efforts and to highlight the importance of their specialized programs.

Botanic gardens fill an important niche in the plant conservation and research world, primarily through the maintenance, development, and improvement of their living collections. This garden aspect of their mission essentially requires a long-term management plan and stability. Likewise, the horticultural and scientific expertise and experience of botanic garden staff is basically irreplaceable as it is derived from the accumulation of observations and knowledge over many years and across an impressive diversity of plant species. This long-term commitment creates a fundamental biological understanding of the plants, their behavior and life histories. In the ecological scale of conservation action, botanic gardens naturally gravitate towards the individual plant end of the spectrum (Fig. 1). While many scientists focus on the forest community as a whole, its dynamics and properties, botanic gardens play a natural and important role by focusing on the individual plant up to the species level. Of course, our efforts should not be entirely limited to activities below the community scale of ecosystems and many botanic gardens are actively engaged in forest restoration (“Ecological Restoration Alliance of Botanic Gardens,” n.d.).

The ecosystem services provided by forests are an emergent property of a large number of trees growing together, interacting as a community, and responding to change. While the broad characteristics of a particular forest type, like its species richness or primary net productivity, can be generalized and estimated accurately, the specific properties of a particular location in that forest can vary greatly depending on species composition and land use history. Similarly, the emergent properties of weather depend upon the specific chemical and physical properties of the molecules and particles that comprise the atmosphere, including the heat, moisture, atmospheric particulate matter, etc. Our ability to predict the weather relies upon increasingly detailed physical models of the atmosphere. Unfortunately, we do not have a great deal of knowledge about the specific properties of trees species and how they interact to produce the emergent properties of a forest and how it might respond to a changing climate and land use. Given the emphasis of many large research projects on forests and their emergent properties, their dynamics and composition, their regeneration and associated ecosystem services, botanic gardens fill a major gap in our study of the basic biology, propagation, care and growth of much of Earth’s diversity of plants. To better understand the long-term dynamics and properties of forests, we need a more detailed understanding of the individual components and how they interact to produce the ecosystem services that emerge from forests. Botanic gardens and the research networks they form can play a critical role in creating that holistic insight into individual tree behavior, growth and response given the changing circumstances and distribution of forests.

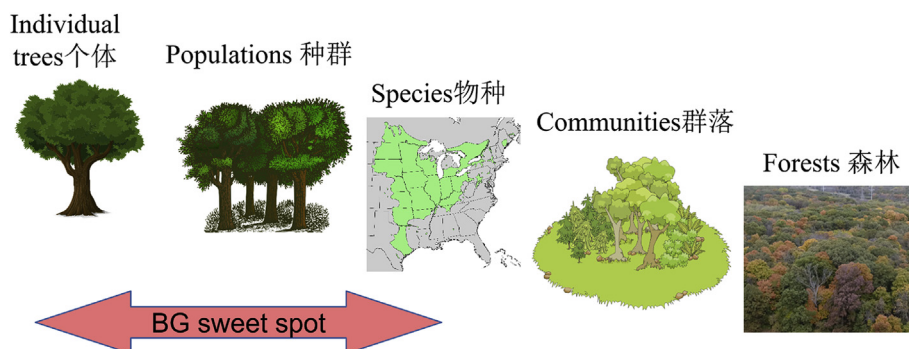


Fig. 1. The “sweet spot” for botanic gardens across the ecological spectrum of conservation action. Botanic gardens have a strong focus on the organism and the behavior of the individual plant. This focus naturally leads to research on the populations and species of these plants.

Focus of botanic garden conservation and research efforts

The other contributions from the Conference on Plant Conservation in China in this special issue of *Plant Diversity* clearly demonstrate the major effort that botanic gardens have made to plant conservation and illustrate the logical focus on the organism for conservation action (Heywood, 2017). Discovering which species are endangered and vulnerable is a powerful first step which leads to strategies about how to conserve, protect, and preserve the diversity represented by these species (Red Listing, 2017). Another path of action has been the ‘ark’ approach, where diversity is gathered, documented and stored, either in seed or living collections (Smith, 2017). Managing these resources through the twin challenges of climate and land-use change will be vital (Entwistle et al., 2017; Chen, this volume). These diverse living plant resources are enormously valuable and provide absolutely tremendous potential for return in the future as humanity strives to feed its growing population and meet global Sustainable Development Goals. These actions are important and a critical part of the botanic garden mission and fall naturally into our realm of expertise, knowledge, and mission.

Because of this long-term commitment to growing, preserving, and improving plant diversity and their benefits, botanic gardens will be some of the best prepared and equipped to create a “Garden Earth” as we enter the Anthropocene. As humans have come to dominate the planet and the basic dynamics of its water, energy, and nutrient cycles, humanity will necessarily have to become more and more committed to sustaining its natural resources (Corlett, 2013; Lugo, 2015). Our valuable plant resources will need to be actively managed, from the intense production environment of monoculture agriculture to the occasional milder interventions necessary to maintain ‘natural’ areas. We will have to manage these lands from a diversity of perspectives while acknowledging the trade-off where this diversity can increase stability and sustainability while decreasing overall efficiency and net productivity. The horticultural staff of botanic gardens often already manage plant and trees across this spectrum of form and function, from manicured ornamental gardens, with carefully bred and esoteric plant varieties, to regenerating natural areas containing wild native species. These skills should be employed to make the global transition to a robust green infrastructure with a healthy and diverse population of trees and plants living in the many environments that humans now inhabit.

The adoption of a Global Strategy for Plant Conservation (GSPC) by the Convention on Biological Diversity in 2002 marked an important advance in raising awareness of the threats faced by plants worldwide, as well as providing, for the first time, a coherent framework for policy and action needed to halt the loss of plant diversity (Wyse Jackson and Kennedy, 2009). The mission of the GSPC is [to be] “a catalyst for working together at all levels - local, national, regional and global - to understand, conserve and use sustainably the world’s immense wealth of plant diversity whilst promoting awareness and building the necessary capacities for its implementation.” The updated 2011–2020 vision of the GSPC is “to halt the continuing loss of plant diversity and to secure a positive, sustainable future where human activities support the diversity of plant life (including the endurance of plant genetic diversity, survival of plant species and communities and their associated habitats and ecological associations), and where in turn the diversity of plants support and improve our livelihoods and wellbeing” (“COP Decision,” n.d.). Botanic gardens, through organizations like BGCI, have been a major proponent of these strategies as they align well with our essential mission.

While the botanic garden focus is on the organism, the projects that botanic gardens impact should not be limited to individual actions but should strive for direct integration into larger policies or provide generalized standards and recommendations for use by other agencies in different sectors, like public works and development. For example, at the Morton Arboretum, tree scientists engage with numerous different agencies, both governmental and non-governmental. Scientists in the Center for Tree Science are working with the Illinois Tollway, a state agency that builds and manages the highways, to improve the tree planting and management standards within the ‘right of way’ of the traffic corridor. In this partnership, the best practises for species composition, soil treatment, and pruning are being determined through experimental trials. The Chicago Region Tree Initiative works with over two hundred municipalities in the greater Chicago area to help communities manage their trees, develop policy recommendations, and interpret remote sensing data to improve the overall quality of the urban tree canopy and to identify gaps and inequities in the green infrastructure. Botanic gardens typically have strong ties to their communities and obviously represent a long-term investment in stability and management. We should build upon these ties to have a positive impact on the quality of life of the public.

Here, we review several major conservation programs, including large governmental efforts and small independently funded efforts, in China and elsewhere, to address several questions:

- 1) What have been the major successes of these programs?
- 2) What have been the major limitations for these programs?
- 3) Could botanic gardens have played a positive and more proactive role?
- 4) Are there “missing” elements of botanic garden outreach and activity and how could these be filled?

Grain 4 green: the world’s largest reforestation effort

Severe flooding along the Yangtze River in 1998 (Ye and Glantz, 2005) initiated the creation of the Grain for Green Program (GGP, 退耕还林还草工程, Tuìgēng huán lín hái cǎo gōngchéng) by the Chinese government in 1999. The GGP, sometimes also known as the Natural Forest Conservation Program (NFCP, 天然林保护工程, Tiānrán lín bǎohù gōngchéng) and the Sloping Land Conversion Program (SLCP, 退耕还林, Tuìgēng huán lín), is the world’s largest government-financed payment for ecosystem services programs (Liu et al., 2008). The GGP program incentivized farmers to plant forests and grasslands in degraded farmland and marginal or barren land. Rehabilitation of steep slopes (greater than 25°) are especially encouraged under SLCP. In addition to reducing soil erosion and increasing biodiversity via conservation and rehabilitation, GGP was also a socio-economic program with the intention to alleviate poverty.

In 1999, GGP program was first implemented in the western parts of the country, where the relatively poor economies were accelerating the degradation of the environment. Starting with Shaanxi, Sichuan and Gansu, GGP gradually expanded to 25 provinces, municipalities and autonomous regions in central and western China. By 2009, the cumulative total investment through the NFCP and SLCP exceeded U.S. \$50 billion and directly involved more than 120 million farmers in 32 million households in the SLCP alone (Ouyang et al., 2016). By the end of 2012, the GGP had converted 9.06 million ha of cropland to forest and had converted 0.64 million ha of cropland to grassland according to the 2012 China Forestry Statistical Yearbook published by the State Forestry Administration (as cited in (Song et al., 2014)). Further, the GGP had

largely increased the soil organic carbon (SOC) by 48.1%, 25.4%, and 25.5% at soil depths of 0–20 cm, 20–40 cm, and 40–60 cm, respectively. Moreover, this carbon accumulation has significantly increased over time since GGP implementation (Song et al., 2014). The Chinese government has committed to extending GGP until at least 2020, with planned retirement of an additional 2.83 million ha of marginal cropland (towards reforestation as well as restoration of shrub and grassland). GGP forests are expected to stay forested beyond the conclusion of the programme (Hua et al., 2016).

In 2012, Chinese Ministry of Environmental Protection and the Chinese Academy of Sciences initiated a national ecosystem assessment. This assessment, collected and consolidated findings from various publications and case studies between 2000 and 2010, was designed to quantify and manage changes in the ecosystem services resulted by the GGP program. As reported by Ouyang et al. (2016), with analyses of data from a variety of sources, including >20,000 multisource satellite images, recorded biophysical data [such as soil, digital elevation models (DEMs), hydrology, and meteorology], >100,000 field surveys; historical records of biodiversity; and special assessments from several government ministries, these overall trends were observed: food production had the largest increase (38.5%), followed by carbon sequestration (23.4%), soil retention (12.9%), flood mitigation (12.7%), sandstorm prevention (6.1%), and water retention (3.6%), whereas habitat provision decreased slightly (–3.1%). Overall, ecosystem services improved from 2000 to 2010, apart from habitat provision. China's national conservation policies contributed significantly to the increases in improving ecosystem services (Ouyang et al., 2016; Song et al., 2014).

Not all greens are created equal

Given the major objectives of the program, the GGP has been a great success and the overall environmental quality for much of the western Chinese rural population has improved substantially. While forests and grasslands have been restored in areas that had been substantially degraded, little distinction was made in the type and composition of the trees planted in these forests. In many cases, monoculture plantations were considered just as environmentally valuable and sustainable as natural wild forest. Additionally, the classification of forests according to different types of subsidies did not have matched the actual ecological and economic benefit of the trees planted (Ahrends et al., 2017). For example, rubber plantations were considered 'ecological' while fruit and nut trees were considered 'economic' forests (Zhai et al., 2013), despite the fact that rubber plantations are far more lucrative. Since more financial incentive was provided to ecological forests, monoculture plantations of rubber were promoted over a more mixed agroforestry. Additionally, the outreach efforts were not always equitable during the major transition in land tenure, leading to women and the poor losing opportunities for improvement (Liu and Cannon, 2011).

A core mission for all botanic gardens is the study, display, and maintenance of plant diversity. No other agency in the world is more knowledgeable about the various properties and characteristics of different plant species and botanic gardens have played a central role in preserving and applying plant diversity throughout the world. The fact that botanic gardens were not involved in the design, development and implementation of the GGP seems to be a large missed opportunity. Similarly, large federal programs in the US have suffered from the same indifference to the power of different greens and the available knowledge base centered on botanic gardens and their associates. Since it was established in 1985, the Conservation Reserve Program (CRP) in the US has prevented more than 9 billion tons of soil from eroding, reduced

nitrogen and phosphorous runoff relative to annually tilled cropland by 95% and 85% respectively and sequestered an annual average of 49 million tons of greenhouse gases, equal to taking 9 million cars off the road. Since 1996, CRP has created nearly 2.7 million acres of restored wetlands. As of 2015, CRP is protecting more than 170,000 stream miles with riparian forest and grass buffers, enough to go around the world 7 times (Stubbs, 2014; USDA, 2015). However, the Conservation Reserve Program in the US suffered from a similar lack of input for plant experts, resulting in a similar pattern where major improvement is gained but an even more ecologically sound and sensible impact was lost (Johnson and Schwartz, 1993).

Just like the GGP, these programs can be a major success given the stated simple objective to reduce erosion and create "forest" and "grassland" but too often they rely on exotic plant species of limited diversity and many of the possible values and benefits of native diversity are lost. More input from those who understand the importance and subtlety of the many different 'greens' is required to obtain the full benefit, not just for people and the basic metrics of environmental quality but for wildlife and biodiversity. While the overarching goals of such large 'payment for ecosystem services' programs may be met by planting any type of tree and thus creating a 'forest', substantial additional benefit would be possible if careful detailed attention were given to 'planting the right green at the right place at the right time'. Botanic gardens are some of the experts who could contribute substantially to choosing the right green.

Policy makers need to be aware that not all greens are equivalent and choosing a different set of species can radically change the overall benefit, even while meeting the major societal goals. In China's 13th five year plan (十三五规划, Shísānwǔ guīhuà), the concept of a 'green' (绿色, Lǜsè) focus is among the country's top objectives. Since the 18th Party Congress, Chinese President Xi Jinping has put forward the notions that "Clean waters and green mountains are tantamount to golden and silver mountains" (绿水青山就是金山银山, Lǜshuǐ qīngshān jiùshì jīnshān yínshān) and that "preserving the ecological environment is equal to protecting the productivity, and improving the ecological environment is equal to developing productivity" (牢固树立保护生态环境就是保护生产力、改善生态环境就是发展生产力的理念, Láo gù shù lì bǎo hù shēng tài huán jìng jiù shì bǎo hù shēng chǎn lì, gǎi shàn shēng tài huán jìng jiù shì fā zhǎn shēng chǎn lì de lǐ niàn) ("CPCNews," n.d.), taking the development of ecological civilization up to a new level, and significantly accelerating the institutional reform, environmental governance, and ecological conservation processes with positive results ("Ministry of Environmental Protection, PRC," n.d.). Given this renewed commitment to a 'green' future at the highest level in the Chinese government, botanic gardens and the large organizations that unite them, like BGCI and CUBG, should be an obvious source of information, expertise, and collaboration in distinguishing among the many types of green to find the right one for the right purpose.

In 2013, the concept of "Sponge Cities" (海绵城市, Hǎimián chéngshì) was launched by the Chinese Government. Sponge cities are cities with an infrastructure that passively collects excess rainfall, and integrates flood control in urban planning ("Xinhuanet," n.d.). With proper design and implementation, infrastructures such as permeable roads, rooftop gardens, rainwater harvesting, rain gardens, green space and blue space (ponds and lakes) can reduce the frequency and severity of floods, while improving the water quality. A "sponge city" will not only be able to deal with "too much water", but also help with the common challenge of "not enough water" in Chinese cities. This type of infrastructure will also reduce the economic losses due to current

urban flooding. These major environmental and conservation efforts, primarily occurring at the city level, should be a natural opportunity for botanic gardens to exercise our expertise and develop our ability to implement green infrastructure on a large scale.

The concept of a sponge city is very attractive to the public and policymakers alike. “But the changes can make financial sense in the long term. When Changde, a city 1,200 km west of Shanghai, replaced 15% of its hard-standing [surfaces] with bioswales, it cut its engineering bill for new drains in half. Sponge cities also come with wider social benefits... environmental groups like it because you're greening the city and local residents like it because you're taking an urban blight and converting it to a community resource.” (Harris, 2015). While some fundamental research has already been performed on different components of the sponge city (Scharenbroch et al., 2016), a great deal of experimentation and study is required to scale up to the massive proposed areas (Pataki et al., 2011). The ultimate success of the main sponge city elements, like biofiltration units, will depend on the quality and expertise in the choice of the tree species and how it varies across the urban landscape. Botanic gardens could play a local role in these efforts by assisting in the scientific design of the important components of the sponge city, such as bioswales.

One of the latest and largest developments relevant to this discussion in China is the proposed JingJinJi (京津冀) area which is a mega-city, consolidating Beijing, Tianjin, and Hebei and planned to support 130 million people (Shepard, 2016). This mega-city will involve a great deal of intentional construction of urban living spaces and green infrastructure. The easiest method would be to clone and plant a short list of tree species known to perform adequately and predictably in this landscape, like the London plane tree (*Platanus × acerifolia*), but relying too heavily on monocultures in the built environment is dangerous. In North America, popular and common street trees, like the American elm and green ash, have been devastated by invading diseases and pests (BenDor et al., 2006; Karnosky, 1979). The urban landscape offers a tremendous amount of niche space and presents a serious challenge to plants and trees in general, it is also complex and chaotic on a small spatial scale. Environmental conditions, like temperature and light exposure and drainage, can change on small spatial scales, from one side of the street to another. The gradual gradients often seen in nature, from wetlands to well-drained lowlands to rocky highlands, do not exist in the urban landscape. We cannot simply choose to be ‘green’ and replicate the same ‘biofilter’ throughout the city. The natural capital of urban trees is tremendous (Willis and Petrokofsky, 2017). To insure this capital performs not only in the short term but continues to perform long after planting, we should determine which “greens” are most appropriate in specific commonly available conditions and develop a diverse set of “greens” to utilize across the city to avoid monocultures. Given the long lifespan of trees, the impact of climate change must also be considered in developing these ‘green’ plans (Entwisle et al., 2017). These efforts require the combination of both basic and applied research and should build on already existing knowledge. Again, botanic gardens are a major resource in relation to these questions and we should actively engage at an early stage in efforts like these to maximize influence and impact. Instilling the principles of robust knowledge and resilient diversity at the beginning will be much more likely to produce good results than trying to fix problems from a rushed and unthoughtful implementation.

Adapting and contributing to conservation by private citizens and NGOs

Ultimately, the central government and its institutes cannot be responsible for all conservation action in China, the ability and

opportunity for private citizens to contribute significantly should be explored. The recent reforms in land tenure, which gave private citizens greater power over how to utilize their land, is an opportunity to engage and influence how these lands are developed (Han et al., 2014; Shen et al., 2009; Xu and Wilkes, 2004). These rural landowners typically have limited experience with markets and they have limited exposure to the various options for improving or maintaining their lands. Like the GGP, specific knowledge and expertise on what to plant and where to plant is required but on a finer and more individualistic basis. The engagement of private landowners is generally difficult (Kamal et al., 2015; Kittredge, 2015) but many organizations recognize that it is an important piece of the puzzle. For example, the Chicago Region Tree Initiative, based the Morton Arboretum, is working with private landowners and managers to incorporate a scientific perspective and to develop a management policy for their lands, which are often missing. How the lessons learned in the West (Hendee and Flint, 2014) might be translated into China is not clear but with increasing liberalization of personal economic choice and activity and the increasing role of philanthropic giving, the potential for positive impact is large.

An interesting and related development in China is the creation of private conservation easements following the model commonly practised by The Nature Conservancy. The first major effort was the creation of a Natural Capital project and the formation of the Laohegou land trust reserve (老河沟自然保护区, *Lǎo hégōu zìrán bǎohù qū*) which has been approved and successfully established. “The first step is to invest in the organic agriculture program to accommodate the increasing number of villagers who are joining, in order to support the local communities’ livelihood in the long run, he said. The second step is for the reserve center to hand over its management rights completely to local communities” (“Mongabay Environmental News,” 2016). While the local attitudes towards this project have been largely positive but the villagers are not happy because of their loss of use. Another challenge, like many conservation efforts around the world, is that the investment and development of opportunities in these natural areas often attract people seeking opportunities, thus increasing the human population and intensifying the land use. These types of opportunities should be explored by Chinese botanic gardens.

In Southeast Asian countries, where non-governmental organisations (NGOs) are more common and active, several local NGOs are actively improving the environment through a ‘BC’ approach. A framework species method for planting trees during reforestation efforts led by the Forest Restoration Research Unit (FORRU) at Chiang Mai University in Thailand has been quite successful (Elliott et al., 2014, 2003). FORRU carries out research to develop efficient methods to restore tropical forest ecosystems for biodiversity conservation, environmental protection and carbon storage. A small team of ecologists and research students in the Science Faculty of Chiang Mai University actively engages with local people to integrate biodiversity conservation into the needs of communities situated in or nearby tropical forests. Based on the concept that if local people have appropriate and sound technical support and are directly involved in all aspects of forest restoration, from planning, to growing and planting trees, they will be empowered and develop a sense of “stewardship” of these restoration projects and will actively participate in caring for and monitoring restored sites, thus reducing the likelihood of subsequent deforestation.

Health in Harmony and ASRI, its Indonesian partner, have been linking human health to environmental health by allowing patients to pay for health care through environmental actions, like providing seedlings, compost, and labor for forest regeneration programs. Communities also receive subsidies if they do not allow illegal logging within their jurisdiction. On the southern border of Gunung Palung National Park in West Kalimantan, they are

engaged in restoring and stabilizing the buffer zone along the park's boundary. This effort requires creating and maintaining nurseries, adapting to local availability of species, and coordinating plantings and maintenance. These efforts all fit easily into the prospectus of a botanic garden. We need to identify these types of activities and promote and adapt and refine them in collaboration with the NGO, local or international. A great deal can be learned through this exchange. This is an under-utilized and often controversial mode of societal action in China but the development of self-organized efforts to improve the living condition and natural value of an area will be necessary. Many of the most successful programs are those with a long history in one place with a strong sense of commitment to the community. We should turn to those who know how to garden, because it requires a long time frame for development and design. We must learn to make plans for the next several decades and create adaptive management techniques at continental and regional scales. A major disconnect can exist in top-down forest restoration efforts and community action and more bottom-up programs are needed: botanic gardens could facilitate and promote this shift in action and implementation (Holl, 2017).

Botanic gardens have the expertise needed for a “Garden Earth”

Big national conservation and restoration programs represent a huge investment in money and resources but little ‘ecological’ planning is involved in the have had a dramatic impact on forest condition and extent and improved fundamental ecosystem services but often the details are neglected, incentives are not properly structured and biodiversity suffers. Botanic gardens could play a role in the early planning of these large federal programs, engaging with policy makers and negotiating grand objectives and best practises. Smaller private and non-profit efforts are typically site and personnel specific but can have tremendous lasting impact locally and their efforts can be replicated and amplified. Botanic gardens should play a role in promoting their efforts and providing expertise as needed. The government is obviously not going to beg for our participation but if the ultimate benefits of diversity and knowledge in planting be demonstrated clearly, then they will better understand why and how botanic gardens could be engaged. Possibly a direct lobbyist position is necessary, as several levels of the government, to monitor the development of opportunities and to make policymakers aware of the contribution that botanic gardens could make to the efforts at improving the living environment. We could play a larger role in governmental and development policies and activities but it will require inserting ourselves into those discussion and conversations.

The majority of popular imagination about our future in the Anthropocene is dystopian (Brunner, 1976), and focuses on the negative impacts of our increasing domination of natural cycles and landscapes, e.g. impending mass extinctions (Kolbert, 2014). But an emphasis on positive approaches and resolutions to the challenges of the Anthropocene is growing (Bennett et al., 2016; Madliger et al., 2017) and we would suggest is necessary. One obvious aspect of the ‘good’ Anthropocene outcome is that it will require a great deal of ‘green’ engineering, placing the right plant in the appropriate place while utilizing as diverse a range of species as possible. This ‘good’ Anthropocene vision essentially amounts to a “Garden Earth” and this garden will only develop with a great deal of planning and careful thought combined with a deep insight and experience with plants (Pataki, 2015). While climate change will be a major factor and has been the focus of much discussion, the changes in land use are often more

immediate and have an even more profound effect on diversity and function of ecosystems. Beyond the city limits, many of the natural processes of migration and dispersal and gene flow are no longer functioning as they did even a century ago and we must accept this rather huge responsibility of maintaining and sustaining as much of these functions as possible or face the consequences of a rather huge collapse. The garden concept encompasses a vast range of objectives and types of plantings and collections. This vision of a “Garden Earth” should include the entire spectrum of the garden concept.

Some recommendations for botanic garden leadership

- Engage locally with a broad range of partners and agencies, across all sectors that affect the green infrastructure.
- Actively lobby for the incorporation of critical knowledge about diversity and function of plants into the construction of the ‘green’ infrastructure.
- Engage globally with other botanic gardens and their networks to promote and develop botanical knowledge and research.
- Incorporate more socio-economic perspectives to improve the alignment of conservation actions with major trends and societal forces.
- Participate in the development of the green infrastructure in the built environment through direct lobbying and proactive goals.
- Enable and assist smallholders and landowners to make informed decisions about land-use and to develop management plans.
- Assist private and NGO agencies to maximize their conservation actions by collaborating and contributing to their ‘green’ efforts.

Appendix A. Supplementary data

Supplementary data related to this article can be found at <https://doi.org/10.1016/j.pld.2017.11.003>.

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