Journal of
Zoological and Botanical Gardens

MDPI

Review

Botanic Gardens in Biodiversity Conservation and Sustainability: History, Contemporary Engagements, Decolonization Challenges, and Renewed Potential

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Abstract: Botanic gardens are increasingly important agents of plant research and conservation. A large number of botanic gardens have been established throughout the globe since the mid-20th century to pursue new socio-environmental missions. Others, with histories that span centuries, have also undergone a deep transformation in the context of growing attention to matters of sustainability. Bridging key aspects of the scholarly literature on the genesis of the botanical garden institution in Europe and its legacy, this article presents the re-invention of these gardens as institutions of conservation, sustainability, and social engagement as they renew their relevance in the contemporary world. This article proceeds by covering three focal points. First, it summarizes the scholarly literature on the emergence of botanical gardens in Europe and their association with the rise of modern science, the nation-state, colonialism, and empire-building. Second, it presents accounts of current scientific and biodiversity conservation endeavours as reflexive engagements with these historical legacies, decolonization initiatives, and new socio-environmental missions. Third, this article points beyond its focus on the historical transformation of the European botanical garden institution, by identifying a more widely encompassing body of scholarship that puts forth frameworks for understanding the current role of botanic gardens on a global scale.

Keywords: botanic garden; history; colonialism; biodiversity conservation; decolonization; science communication; education; SDG; socio-cultural

Citation: Neves, K.G. Botanic Gardens in Biodiversity Conservation and Sustainability: History, Contemporary Engagements, Decolonization Challenges, and Renewed Potential. *J. Zool. Bot. Gard.* **2024**, *5*, 260–275. https://doi.org/10.3390/jzbg5020018

Academic Editors: Donald Rakow and Christopher P. Dunn

Received: 1 March 2024
Revised: 15 May 2024
Accepted: 20 May 2024
Published: 31 May 2024

1. Introduction

Scholarly research demonstrates that botanic gardens have played instrumental governance roles throughout the course of their existence, and continue to do so today [1,2]. At their inception, they facilitated the emergence and consolidation of the modern nation-state in Europe, as well as supported European colonialism and empire-building processes [3]. They have also been important in the establishment and consolidation of nations in the global south in a post-colonial world. Since the late 1980s, botanic gardens have been engaged with the governance of plant biodiversity worldwide [4,5]. They have sought to refashion people's relationships with plants, in some cases with higher success than others [6–10]. Today, botanic gardens and kin institutions constitute a complex web of networks at a planetary scale, through which knowledge, resources, and living plants are shared. In so doing, the botanical garden institution nurtures sustainability at the intersection of human and plant diversity [11,12]. From this perspective, botanic gardens are far from the quaint self-directed institutions that some perceive them to be.

Nowadays, a vast array of institutions can fall under the label of a botanic garden depending on defining criteria. In the introduction to the most comprehensive study to date on the role of botanic gardens in biodiversity conservation, Galbraith points out that "they range from small institutions of a few hectares in size that are sometimes associated with universities or collages [. . .] to very large, free-standing organizations that [. . .] may own and manage natural areas in the hundreds of thousands of hectares" [13]. Moreover,

Galbraith explains, botanic gardens "vary in their missions, objectives, user groups, facilities and program types, and organization models" [13]. Adding to this heterogeneity, botanic gardens can overlap with kin institutions in the preservation of plant diversity, research, and knowledge dissemination. Many zoos, for instance, include gardens with vast collections of plants that are the object of scientific research, preservation, and educational projects [14–16]. So do some historical parks and natural science museums, amongst others [17].

The modern botanical garden institution [18] came into existence a little over 400 years ago with the establishment of the first gardens dedicated to the systematic study of medicinal plants. Having evolved out of earlier monastic gardens, modern botanic gardens appeared at the rise of modern science and European encounters with plant worlds previously unknown in Europe. Botanic gardens played foundational roles in classifying these plants into European systematics, as well as in determining possible economic advantages to colonizers associated with the commercialization of these plants [19]. Botanic gardens also developed techniques to acclimatize plants across distinct geographic regions which, in turn, allowed many European countries to draw enormous gains from establishing new crop-based economies on a global scale [20,21]. While this brought incalculable gain to European imperial nations, it had devastating effects in many colonial territories as local knowledge practices and systems of livelihoods were displaced and/or outright demolished. Grey and Sheikh explain that "colonial botany involved a process both of extraction and erasure: the extraction of local knowledge, plants, information and labour; and an erasure of Indigenous knowledge and ecological practices" [22].

In time, botanic gardens came to play key roles in the processes of empire-building that are associated with the consolidation of modern nation-states in Europe. At the height of their entanglement with these dynamics, botanic gardens were connected with one another on a truly global scale. These connections amounted to a complex network of collaborations, material exchanges, and knowledge flows that remain one of the greatest assets of the botanical garden institution to this day.

Throughout the latter part of the 20th century, the botanical garden institution reinvented itself in the context of growing environmental concerns [23–25]. With the recognition of global biodiversity loss that is associated with the environmental movements in the 1960s and 1970s, an expanding number of botanic gardens began to transform themselves as institutions of plant biodiversity research and conservation. In many places, and most notably, in the global south, new botanic gardens were inaugurated specifically to tackle this issue. As a collective, these gardens have made extraordinary contributions to socio-ecological sustainability, to which the limited scope of a journal review article cannot do justice. In fact, such an undertaking was recently published in the form of three volumes that provide state-of-the-art, in-depth, accounts of these botanical garden contributions. This collection of volumes is highly recommended for anyone seeking to obtain an in-depth comprehensive view of contemporary botanic gardens in biodiversity conservation [26].

The establishment of Botanical Gardens Conservation International (BGCI) and its leadership in the development and implementation of a Global Strategy for Plant Conservation (GSPC), further solidified the status of botanic gardens as significant agents in the mitigation of plant biodiversity loss [27]. In the process of these changes, many botanic gardens have embraced social missions that recognize the inextricable dynamics that connect human and plant worlds, on which rests the sustainability of earth's ecosystems [28–30].

As botanic gardens re-invent themselves as institutions of global sustainability, grounded in principles of social equity [31] and environmental justice, they are often confronted with the legacies of former colonial arrangements [32,33]. This matter has become increasingly important in recent years, where botanic gardens formerly associated with colonial endeavours are now embracing highly productive conversations on what decolonizing their institutions may entail. Arguably, taking steps to understand the conundrums that this may pose is highly pertinent. With their rich history and current heterogeneity, botanic gardens currently face challenges and exciting opportunities for their continued relevance vis-à-vis contemporary biodiversity conservation demands. The main

contribution of the present review is to situate the extant scholarly literature on botanic gardens in relation to the fruitful momentum that this reflexivity affords.

To this end, this article proceeds by covering three focal points. First, it summarizes the scholarly literature on the emergence of botanical gardens in Europe and their association with the rise of European modern science, colonialism, and empire-building. Second, it presents accounts of current scientific and biodiversity conservation endeavours as reflexive engagements with these historical legacies, decolonization initiatives, and new socio-environmental missions. Third, this article points beyond its focus on the historical transformation of the European botanical garden institution by identifying a more widely encompassing body of scholarship that puts forth frameworks for understanding the current role of botanic gardens on a global scale.

2. Historical Evolution of the Botanic Garden [18]

It is standard practice in the scholarly literature to present the history of botanic gardens in a sequential fashion, dividing it into major periods that are each characterized by specific central mandates at botanic gardens. There is some variation in how these periods are divided, depending on the author's focus and/or the source's main purpose [34]. For the sake of brevity, the present overview condenses the historical evolution of botanic gardens into two main stages. The first covers the foundation and consolidation of the botanical garden institution in Europe and its concomitant embroilment with colonialism and empire-building. The second focuses on their relatively recent confrontation with colonial legacies in the form of efforts to engage with decolonizing the botanical garden institution while it also re-invents itself in relation to biodiversity research and conservation. This complicates the linearity of accounts of botanic garden histories by pointing to reflexive engagement with their historical legacy.

The modern botanic garden institution came into existence in late 16th century Europe. Botanic gardens owe their origins to monastic and physic gardens. These were sites where plants were grown for practical purposes related to nourishment and health, but also as means to reflect on biblical discussions of God's will as manifested through creation [35]. These questions acquired renewed pertinence with the arrival of Europeans to the American continent and their encounters with peoples, ecosystems, and plants previously unknown to Europeans. The quest was to understand how these 'newly' discovered kingdoms might be made to fit into extant European understandings of 'God's intended order of things'.

The establishment of the first botanic garden proper in France, Germany, Italy, the Netherlands, and the United Kingdom in the mid to late 1500s reflected a steady shift away from theological questions about the nature of plants. Expanding on their precursor—the physic garden—these early botanic gardens were dedicated to the scientific study of medicinal plants. By the 1600s, botanic gardens were well established as centres for training medical doctors in the use of medical plants. Early medical doctors based much of their profession on mastering pharmacological concoctions for healing purposes. For this reason, many botanic gardens were associated with universities, which further contributed to their establishment as sites of scientific pursuit. By the 1700s, medical schools became autonomous from botanic gardens. The study of plants in and of themselves became a separate field under the aegis of scientific botany. By the late 1700s, and especially under the influence of Linné's work at Leiden, botanic gardens became centrally concerned with the systematization of plant nomenclature, taxonomy, and propagation [36]. Many programs that combined scientific research with training university students in modern botany were developed. At this historical juncture, botanic gardens also focused on the study and classification of new plants that were introduced to Europe mainly through colonialism [8,19].

Throughout the 1800s and early 1900s, botanic gardens in Europe continued to play instrumental roles in colonialism and empire-building [3,37,38]. They developed the necessary know-how to facilitate plant adaption across different ecosystems and climates. This work of plant acclimatization was essential for colonial nations seeking to solidify their

domain across vast geographic areas in the global south [39]. It allowed nations to build crop-based economic empires that spanned the globe [40]. For example, the Amazonian rubber tree native to areas that were once under the Portuguese domain was acclimatized to grow in areas in East India under the British domain [41]. The latter became a monumental source of wealth for British entrepreneurs. Similar examples abound of highly lucrative crops such cotton, coffee, and tea. Not only did this disrupt existing plant-based economies, but local people were also often prevented by force from developing alternative, adaptive, means of livelihood, as the case of Borneo in the Indo-Malay region illustrates [42].

These processes were facilitated through the introduction of new technologies that allowed tropical plants to survive and thrive in the frigid climates of the global north. The most prominent of these inventions was the heated greenhouse, which brought unprecedented advantages to these nation-states. On the one hand, greenhouses afforded European nations opportunities to amass a vast array of living plants collected all over the world [43,44]. On the other hand, it accelerated the development of economic botany, which studied the potential use of plants for profit [45]. This discipline operated alongside ethno-botany, whereby traditional knowledge practices were also collected and housed in European botanic gardens. As a whole, these developments contributed to the consolidation of European colonial hegemony [19,46]. Not only did they facilitate the exchange of plant materials on a global scale, they also promoted the centralization of invaluable plant knowledge within European botanic gardens [47]. Many gardens in the global north possess large archival collections that still house these materials [48–50].

At the height of modern European colonialism in the late 18th and 19th centuries, the reach of botanic gardens in European metropolises extended into colonial holdings where satellite botanic gardens facilitated processes of plant extraction and acclimatization. Not rarely, satellite gardens, such as, for example, Kirstenbosch National Botanical Garden in South Africa, experienced colonialism at the hands of a succession of colonial powers [33] as the result of the ebbs and flows of shifting imperial geopolitics.

3. The Re-Invention of Botanic Gardens in the Age of Biodiversity Conservation and Post-Colonial Dynamics

In recent decades, botanic gardens have been reconstituting themselves as organizations of plant curation, scientific research, and biodiversity conservation [26,51–53]. This shift began in the 1980s in response to the rise of environmental movements of the 1960s and 1970s. It was consolidated with the establishment of Botanic Gardens Conservation International (BGCI) in 1987 [54–56]. BGCI operates as an umbrella organization that brings botanic gardens and kin institutions around the world into a network of collaboration to preserve plant ecosystems on a planetary scale [57]. For example, BGCI has spearheaded the creation of Global Strategies for Plant Conservation (GSPCs) in step with the Convention of Biological Diversity (CBC) [58]. It implements an operational framework that guides a wide range of local, national, and international stakeholders in pursuit of plant sustainability. The GSPC encompasses five key thematic priorities. They are (1) the understanding, recognition, and documentation of plant diversity; (2) the urgent and effective conservation of plant conservation; (3) the sustainable and equitable use of plant diversity; (4) the promotion of education and awareness of plant diversity, as well as the role of plant diversity in sustaining livelihoods and life on earth in general; and (5) the development of the necessary capacities and public engagement for the successful implementation of the GSPC. As a subset of the GSPC, many countries have developed National Strategies for Plant Conservation (NSPCs) that implement the GSPC with attention to national and regional plant diversity ecosystem dynamics [59].

These transformations have had a major impact on the core missions of botanic gardens [60]. On the one hand, botanic gardens have developed and expanded biodiversity research and conservation mandates. In some cases, this includes the creation of entirely new science departments that rely on new technologies and expertise, as well as greatly expanded approaches in the training of personnel with expertise in plant conservation

science [61,62]. On the other hand, at the end of the first decade of the new millennium, botanic gardens began to embrace social missions as a form of engaging wider audiences in socio-ecological sustainability [63,64]. The focus of these projects ranges from knowledge dissemination to lay audiences, the promotion of urban food security, and to the preservation of cultural diversity as inextricably linked to biological diversity. The goal is to promote and nurture more sustainable relations between people and plants [44].

Alongside these transformations, many new kinds of botanic gardens were founded throughout the 20th century and early 21st century. In contrast to the European historical and colonial model, many of these new gardens were created to serve a multitude of purposes that are not restricted to scientific research. This includes, for example, the preservation of local/traditional forms of plant knowledge and use or the restoration of indigenous practices of environmental stewardship [65]. The Dilla University Botanical and Ecotourism Garden, Dilla, Ethiopia, is an example of a highly successful contemporary garden with a socio-environmental mission. Not only has the garden reached the highest standards of scientific research and biodiversity conservation, it also seeks to support sustainability and eco-tourism in the region [66]. From this perspective, the contemporary botanical garden institution is far more widely encompassing and inclusive than that of earlier European counterparts [67].

The dynamics that once characterized relations between botanic gardens in the global north and botanic gardens in the global south have also changed considerably with the independence of former European colonies. Owing in part to this, engagement with colonial legacies is becoming increasingly important within the botanic garden institution [68]. Leading botanic gardens such as, for example, the Royal Botanic Gardens KEW, are reshaping the nature of their collaborations with gardens in nation-states that were once integrated into the British imperial domain.

A key item of discussion at this juncture refers to the power dynamics that currently take place in biodiversity research and conservation initiatives [2]. While the current ethos is to develop equitable and mutually beneficial partnerships, there is the risk that former colonial dynamics are reproduced—however unintended this may be. Specifically, the centralization of biodiversity knowledge, scientific resources, and plant genomes (to name but a few) at former colonizer botanic gardens may put the latter at an advantage in relation to botanic gardens in regions and/or nations from which these biodiversity knowledge practices and plant genetic materials are extracted [69,70]. Simply put, the convergence of a vast pool of resources into centralized holdings in the global north comes with considerations about who can access these resources and how.

The Millennium Seed Bank at Royal Botanic Gardens Kew (Wakehurst) in the U.K. is an illustration of how this delicate balance comes into play [71]. While The Millennium Seed Bank serves the inestimable mission of preserving 2.4 million seeds from around the world for future planetary biodiversity needs [72]; the genome pool it contains is centralized at a single site within a former colonial botanic garden. To be sure, the Seed Bank operates on principles of mutual benefit to all participating gardens that have been carefully conceived and implemented [73]. But in a world of mutating geo-biopolitics, it is crucial to ensure that these balances remain in place.

Additionally, from a wider contextual perspective, scholars have demonstrated that current mainstream understandings of environmentalism and conservation have deep colonial roots that reflect Western values and interests [43]. This, for instance, had an impact on the African continent during the 1990s and early 2000s when a form of neoliberal biodiversity conservation sought to implement Eurocentric visions of nature preservation that were often at odds with local knowledge practices and priorities [74,75]. The literature on botanic gardens confirms that indeed colonial dynamics can be reproduced in the context of contemporary biodiversity conservation, as exemplified in South Africa [33,76], British Columbia, Canada [65], and Palestine [77,78].

To counter these risks, better recognition of the importance of lay expertise and respective knowledge practices, as well as matters of intellectual ownership, are of great

importance in decolonization debates [79–81]. Some botanic gardens are also beginning to rethink the status of archival collections obtained through colonial rule. This can pose a considerable challenge, but it can also offer exciting possibilities [82]. Principles such as reciprocity and equity have been embedded in new collaborations between gardens in the global south and the global north. These principles translate, for example, into practices meant to ensure that both stand to gain from collaborative processes. Moreover, new debates are emerging on whether or how botanic gardens may engage with decolonization mandates that dismantle historical hierarchies and power differentials that allowed for the extraction of plant materials and knowledge from the global south and their concomitant appropriation to serve the interests of colonial rulers [83].

The issue of decolonizing the botanic garden is highly complex. Only relatively recently has the scientific literature begun to engage with the issue. Given the emergent state of scholarly studies on decoloniality [84,85] within the botanical garden world, any attempt to provide an overview of the matter and/or organize it into broad categories of intervention is at best preliminary at the date of writing this article. Nevertheless, two broad thematic areas illustrate decolonization matters within the realm of the botanical garden institution as follows: the independence of former European colonies and the discussion of the status of botanic gardens as 'museums' that host plants, objects, and knowledge records obtained through colonial extraction.

The first decolonization thematic at botanic gardens refers to the end of modern European colonialism. As former colonies gained independence they also took control of satellite botanic gardens that had been built to serve colonial interests such as those associated with economic botany or plant acclimatization, for instance. The botanical garden of Rio de Janeiro is an early example of a repurposing of botanic gardens in a post-colonial context. The garden was founded in 1808 by Regent D. João of Portugal when the Portuguese Royal family and its court left Portugal and went to Brazil in the face of Napoleon's imminent invasion. The Garden's colonial purpose was to acclimatize plants associated with Portugal's prominent role in the spice trade and, in so doing, expand Portugal's economic prowess. With Brazil's declaration of independence in 1822, however, Rio's botanic garden initiated a process of transformation whereby its core mandates became associated with the newly forming Brazilian nation-state and its own eco-nationalist projects [86,87].

It is important to note that the decolonization of botanical gardens in post-independence nations was a highly heterogeneous process that was not always fully emancipatory within projects of post-colonial nation-building. For example, some argue that New Zealand's early post-colonial revisioning Christchurch Botanic Gardens promoted eco-nationalist visions of human–nature relations that reflected white settler ideations. At the time, these sanitized the colonial expropriation of indigenous land, livelihoods, and knowledge practices, thus setting barriers to the promotion of indigenous visions of New Zealand's past, present, and future within the garden's early decolonial engagements [88]. Engaging reflexively with this legacy, Christchurch Botanic Gardens now grapple with revisioning notions of 'nativeness' [89].

The second illustrative thematic of decolonization at botanic gardens echoes debates that have been taking place within the museum world since the 1990s. This decolonial thematic was long overdue for botanic gardens. They are especially relevant to botanic gardens on two levels. First, botanic gardens are living arcs [90] that can be seen as living plant museums. Many of these plants were obtained through colonial relations of extraction and, in many cases, these can be plants that are extinct in their ecosystems of origin. Second, many colonial botanic gardens have also functioned as museum-like institutions that curated large collections of artifacts. In fact, some actually displayed parts of these collections in the form of ethnographic museums that were open to the public, as is the case of Kew's People and Plant museum.

Kew's economic botany collection alone contains more than 100,000 objects "that tell stories about how daily lives are lived, how human moments are celebrated and how

communities are built and defended" [91,92]. Crucially, decolonization debates must keep present that such stories are frequently those of peoples whose knowledge and practices were erased by European colonialism. As Grey and Sheikh point out, "a plant that was brought to an institution such as Kew Gardens would be given a Latin name, and in the process, the local knowledge that existed about that plant would be extracted and the source of the knowledge erased. By supplanting the local name, the world in which that plant existed also disappeared". This association is also detectable in cases where plants known to Indigenous peoples were appropriated and renamed into a nomenclature system that paid tribute to male European explorers, patrons, politicians or even, in the case of the *Hibbertia*, "a man who made his fortune from slave trading" [93]. This form of epistemic violence is compounded by the fact that these relationships of extraction were part and parcel of much wider systems of violence characteristic of colonialism that also include slavery, and in which botanic gardens such as the St. Vincent Botanic Garden (Kingstown, St. Vincent, Caribbean) were directly involved [94].

4. Contemporary Missions of Botanic Gardens

The transformations that took place in the latter part of the 20th century and early 2000s are reflected in the revision of the historical mandates of the botanical garden institution [95]. These include the development of new orientations for scientific research and the reconceptualization of horticulture at botanic gardens to serve purposes of biodiversity conservation. In turn, new missions have emerged as botanic gardens take on new social roles [96] and shift toward a more widely inclusive engagement with their audiences.

4.1. Science, Research, Horticulture, Education, and Conservation

Scientific and formal educational activities remain a key mandate at many botanic gardens [97]. For BGCI, the conduct of science remains a defining trait for the recognition of botanic garden institutional status. Within this framework, scientific botany has retained its historical importance as science departments continue to study plant structure and physiology, distribution, and classification. However, whereas medicinal, economic, and ethno-botany were central activities at earlier botanic gardens, contemporary botanical research tends to prioritize matters of environmental sustainability. This includes research on plant genetics, propagation, ecosystem dynamics, plant diversity, biodiversity conservation, and adaptation to the planet's changing climate [98]. Within this context, botanic gardens have also grappled with their unintended introduction of invasive species as part and parcel of their historical legacies. New codes of practice have been developed and implemented to monitor and counter the risk of invasive plants, which are often accompanied by public education programs on the matter [99].

The development of novel methods and technologies for the study of plants and plant ecology has also impacted the ways in which plant science is carried out at botanic gardens. The study of plant ecology and reproduction has accelerated exponentially in recent decades with the development of theoretical modelling. These innovations allowed scientists to explore multi-scale interactions over time among plant genetics, ecology, pollination, and reproductive system evolution. They "paved the way for a large number of experimental studies in the laboratory and field, merging pollination biology, quantitative genetics, comparative biology, phylogenetics, population genetics and, most recently, genomics" [100] (p. 999).

The adoption of new scientific methods and technologies at botanic gardens (such as advances in DNA techniques), has enhanced their potential contribution to the mitigation of climate change. For instance, DNA research can identify the role that specific genes may play in rendering plants better adapted to withstand drought and hotter climates. These studies have the potential to support the alteration of plant genetic material toward greater resiliency in a world where average temperatures are expected to continue to increase. While these developments could be of great importance for the future sustainability

of agriculture, these research activities also carry the potential for significant economic impact—especially for the nations leading such research.

When it comes to plant DNA material, some botanic gardens host invaluable collections not only in the form of living plants but also stored in herbaria. These archives contain samples of plants that are currently threatened or even extinct, but which still harbour genetic material that could eventually be of use. A large number of the herbaria that were produced in the past 400 years are stored at botanic gardens in the global north. The use of genetic material stored in herbaria raises questions about the politics of the colonial frameworks within which they were collected. The content that now rests in herbaria was often extracted via inequitable colonial relations that favoured the interests of colonial rulers in unequal systems of exchange and/or forceful extraction. At a juncture where decolonization is increasingly recognized as an important socio-political issue, the question becomes—who gets to make decisions about and benefit from the use of herbaria in contemporary science, as well as who stands to gain from its applications and how.

As institutions of cutting-edge research, some botanic gardens are accredited centres of teaching and learning from entry levels all the way to the highest levels of graduate study. A large majority of botanic gardens provide educational programs for lay audiences that include both children and adult learners [101]. These programs cover a very wide range of learning possibilities, from teaching children the basics of plant seeding and growing, to teaching adults how to combine the pursuit of ornamental aesthetics, food security, and biodiversity. As accredited institutions of formal training and teaching, botanic gardens also offer a wide portfolio of learning possibilities at undergraduate, graduate, and post-graduate levels. This is particularly true of botanic gardens that are associated with universities.

In turn, botanic gardens are major tourist attractions, which allows for a high volume of educational contact points to take place. The potential to reach very wide audiences is therefore very high at these institutions. This potential can also be enhanced through digital platform campaigns. The latter is, in fact, aligned with innovative learner-centred educational programs that promote forms of educational design that meet learners in their habitual use of digital media, thus increasing the likelihood of effective contact point delivery. Indonesian botanical gardens have relied on this paradigm successfully to reach younger audiences, especially among millennials [102].

In the past, scientific knowledge practices at botanic gardens were favoured over informal lay knowledge practices—often referred to as traditional ecological knowledge [103]. The latter was often dismissed as not relevant or rendered invisible beyond the archives into which they were collected. This is ironic if one considers that a great deal of what is now recognized as scientific knowledge within the history of botanic gardens was developed with the help of local inhabitants in colonial territories. In recent years, however, the value of the kinds of lay expertise has been recognized as crucial in the support of contemporary biodiversity conservation [104]. Scholars have shown that cultural diversity is intimately associated with the preservation of biological diversity. While there is still a great need to widen awareness of these associations, the complementarity of lay and scientific expertise is increasingly recognized as a vital aspect of global biodiversity conservation—including in botanic gardens.

Alongside these developments, horticultural activities have retained their prominence in botanic gardens. This constitutes no surprise. The practice of cultivating and tending to plants has been a central feature of the botanical garden institution since its inception. To this day, ornamental displays attract a large percentage of people who visit these gardens. They are a key source of revenue at botanic gardens and one of the major drivers in the continuing expansion of the garden tourism industry. The instrumental role that horticulture plays in relation to science endeavours at these institutions, however, is far less visible to the average visitor despite the existence of interpretation materials that highlight these contributions.

To be sure, scientific investigation and horticulture continue to go hand in hand at many botanic gardens. It can be said that horticulture is the applied dimension of plant science [105]. This role is exceedingly important in the context of biodiversity conservation and climate change mitigation and adaptation. Experts trained in horticulture are often tasked with the challenge of finding ways to reproduce and propagate plants that have not yet undergone processes of 'domestication'. This is highly important work in cases where specific plant species are nearing extinction, as well as in the context of ecological restoration projects. Horticulturists also possess the necessary expertise to work on the strategic reproduction of specific plants with the goal of selecting traits that render these plants more resilient to specific contextual alterations and, therefore, more adaptable to changes in climate and/or ecosystem dynamics.

As an extension of all these activities, botanical garden biodiversity conservation materializes in two main forms. They are in situ conservation and ex situ conservation. Translated from Latin, in situ means 'in place'. It refers to conservation performed within ecosystems with the goal of preserving and/or restoring plants in the endemic settings from which they evolved [106]. Ex situ refers to the conservation of plants outside their original ecosystems [107]. More often than not, this refers to the plant collections that are held at botanic gardens [108]. Many are plants extracted and collected from a variety of locations around the world [109]. Typically, this is the case of botanic gardens situated in nations that were former colonizers, as described earlier in this article. While many associate former colonial botanic gardens in Europe as large repositories of ex situ conservation, examples abound from many countries around the world. The Acharya Jagadish Chandra Bose Botanic Garden in Howrah, India, offers a critically important example of ex situ conservation in protecting several IUCN red list species [110].

In situ and ex situ conservation practices are often mutually supportive [111]. It is not uncommon for botanic gardens to rely on plant collections that they host ex situ for the reproduction of specimens that go into restoration initiatives in situ. It is important to note that this can entail plant species that are considered all but extinct with only a few specimens remaining in existence ex situ [112]. This reality has led to new and exciting collaborations between botanic gardens in the global north and botanic gardens in the global south [113]. Highly important—and successful—biodiversity conservation and restoration initiatives have taken place in this context [25,114,115]. Nevertheless, questions can emerge about the potential for power imbalances to develop among botanic gardens that inadvertently reproduce dynamics that echo those that characterized former colonial relations [1]. For example, collaborations among gardens could entail the extraction and centralized storage of knowledge practices in an inequitable fashion. Gardens operating within a decolonial framework are particularly attentive to such possibilities and engage reflexively to avoid their occurrence [116]. KEW Gardens has pioneered the digitization of its archives and collections as a strategy to make these resources more widely accessible, therefore rendering knowledge-sharing practices more equitable.

In light of these important roles, some argue that botanic gardens stand to expand their relevance even further as the 'Anthropocene' continues to unfold. China provides illustrations of best practices in this context. One example is the Grain for Green case, 'the world's largest reforestation effort' [117]. Following devastating floods along the Yangtze River in 1998, the Grain for Green program created incentives for farmers to mitigate land degradation and erosion by planting forests and grasslands. Cannon and Kua, who have performed extensive research on this project, point to the role that botanical garden knowledge can provide in assuring that such large-scale projects rely on plant material that is not only adapted to local ecosystem dynamics but can also enhance the provision of ecological services [117].

4.2. Social Engagement

At the dawn of the new millennium, botanic gardens began to expand their approaches to plant biodiversity to also include engagement with socio-cultural issues pertaining to

environmental sustainability [118–123]. A 2010 landmark report commissioned by BGCI, the Leicester study [121,124], was a turning point in this context. It identified possibilities for new forms of botanical garden engagement with general audiences and how these goals might be achieved [125]. The report's core focus was the U.K., but many of its conclusions are applicable to a vast array of botanic gardens beyond Europe and the global north.

The study drew attention to the untapped potential of botanic gardens. It suggested that botanic gardens could play more prominent roles in educating general audiences on the importance of preserving plant biodiversity, reconnecting people to plant worlds, and providing greater insight into how citizens might themselves contribute to plant preservation [124,126]. The study recommended that botanic gardens achieve these objectives by working "in partnership with their local communities and addressing contemporary concerns like climate change" (Towards a New Social Purpose: 2). Moreover, the study indicated that botanic gardens could facilitate the materialization of key goals in the Global Strategy for Plant Conservation (GSPC) by collaborating with communities of lay experts beyond the walls of the botanical garden. At the time of the study, many botanic gardens had amply demonstrated their capacity to tackle aspects of the GSPC that require scientific expertise in plants and plant ecology. One of the chief outcomes of the Leicester study was to show that botanic gardens could also make crucial contributions to GSPC mandates that require attention to the socio-cultural dimensions of biodiversity conservation.

One of the additional contributions of the Leicester study was to unveil challenges that confronted botanic gardens in the U.K. and most likely shared by many of the classic botanic gardens in Europe. The main problem revolved around audience perceptions of historical botanic gardens as inward-looking, elitist institutions that implicitly reflected the sensitivities of 'white, middle class, older' visitors. The presentation of plant nomenclature in Latin and the communication of science in technical language were examples of practices that sustained the image of botanic gardens as unwelcoming to visitors from distinct backgrounds and with distinct motivations. The recommendation that came out of the Leicester study was that botanic gardens ought to strive to become more socially inclusive and equitable and rethink their core missions accordingly.

It is important to note that given its U.K. focus, the Leicester study was not mandated to explore or account for botanic gardens beyond the European context. As such, it does not include botanic gardens that have—from their inception—been dedicated to carrying out socio-cultural ecological missions. In the global north, the Montreal Botanical Gardens in Canada, founded in 1933, is an early example of this trend. In turn, a large percentage of the botanic gardens that were inaugurated throughout the global south between 1992 and 2023 and dedicated to biodiversity conservation seem to include social roles at their core [34]. The latter is in fact captured in BGCI publications that provide detailed accounts of the richness and variety of projects in existence globally. These botanic gardens carry out critically important work in pursuit of socio-environmental sustainability. Arguably, this helps explain the more general resiliency of the botanic gardens in the 21st century and their proliferation in the global south.

The Leicester report was unambiguous in its position that the future survival of the botanic garden institution might very well depend on its ability to remain socially relevant in the context of growing concerns with our planet's environmental status and related matters of global inequity. Alas, the report also acknowledges that the capacity to do so varies greatly among different botanic gardens along the lines of financial resources, institutional willingness, and/or know-how and location. This is a highly consequential state of affairs, especially for botanic gardens that face difficulties in transforming themselves to adapt to new historical demands—whether it is due to lack of resources or to internal divisions within botanic gardens concerning the conceptualization of the institution's future.

In response to the Leicester findings, and noting that the conservation of plant diversity "is intrinsically linked to global issues including poverty, human well-being and climate change" [121] (page 2), BGCI invited botanic gardens to re-imagine their philosophies, missions, and practices accordingly. Success in obtaining a grant from the Calouste

Gulbenkian Foundation added momentum to BGCI's efforts in this context. It provided the financial resources for BGCI to launch an initiative that sponsored six pilot projects at botanic gardens in the U.K. (https://www.bgci.org/our-work/projects-and-case-studies/communities-in-nature-growing-the-social-role-of-botanic-gardens/ accessed 6 February 2024). These experimental projects were to be assessed as a baseline for expanding botanical garden social engagement on a much larger scale through BGCI's global network. Titled "Communities in Nature" the pilot program ran from 2010 to 2015 and was highly successful. It demonstrated that botanic gardens can de facto develop and implement activity programs that engage communities meaningfully and productively to achieve goals that simultaneously serve social and environmental purposes [64]. Building partly on the project's success and lessons learned, BGCI was indeed able to scale up the approach to a global level and it "resulted in this approach being embraced as a foundation to all of BGCI's public engagement work" (same link).

Between the global expansion of the number of botanic gardens that were founded to serve socio-environmental roles and the adaptation of older 'traditional' botanic gardens to these purposes, the botanical garden institution has taken on a particularly significant role in relation to the United Nations Social Development Goals (SDGs) [127,128]. In the words of Dr. Paul Smith (BGCI Secretary General) in a 2018 editorial for BGCI's flagship journal, botanical gardens have approached SDGs by "highlighting the intersections between plant diversity and sustainable development" [62] (page 2). In the same edition, Suzanne Sharrock (Director of Global Programs BGCI) provides an illustrative table with examples of the impressive array of contributions that botanic gardens have achieved in this context—which cover all 17 SDG goals [129]. From the goal of ending 'poverty in all its forms everywhere' (SDG1), through ending hunger and achieving food security while promoting sustainable agriculture (SDG2), to reducing 'inequality within and among countries' (SDG 10), and taking action to combat climate change and its impacts (SDG 13)—to name but a few.

Although many botanic gardens in the global north and in the global south continue to grapple with the histories and legacies of European colonialism, with financial strife and the challenges of deepening environmental crisis, the successful adoption of new social–environmental roles has endowed botanic gardens with renewed contemporary relevance. It attests to the continued resiliency of this institution after 400 years of historical adaptations and transformations.

5. Concluding Thoughts

The botanical garden is a resilient institution that has adapted to a multitude of historical transformations. There is good reason to expect that botanic gardens will continue to play important roles in promoting the conservation of plant biodiversity and in helping nations around the world adjust to climate change. The success of the botanical garden institution in this context will very likely depend on its ability to continue to bridge socio-cultural realities with ecological dynamics. To be sure, there is growing consensus that the complexity of environmental problems like biodiversity loss and climate change calls for greater holism as a move beyond reductionist approaches to 'society' and 'nature'. In doing so, botanic gardens will align with globally leading institutions of environmental governance such as The Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services (IPBES) and the UN Environment Programme (UNEP), while continuing to offer unique sets of expertise in the preservation of socio-cultural and biological plant worlds.

Funding: Research informing this article was generously funded by the Social Sciences and Humanities Research Council—Canada (SSHRC) file 435-2016-1099.

Conflicts of Interest: The author declares no conflict of interest.

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