Chapter 3
Botanical Gardens: A Reliable Tool for Documenting Sustainability Patterns in Vegetative Species

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Abstract Gardens are mapped out areas where plants like flowers, trees, spices, herbs, fruits, or vegetables are grown and/or cultivated for the impetus of conservation, aesthetics, or scientific studies. The specific role of botanical gardens all over the world is repositories of diverse collections of functional and utilitarian plants in their gardens and seed banks. Botanical gardens help increase public awareness of threats to plant diversity and promote education on biological conservation and preventing biodiversity loss while achieving sustainability and preventing extinction of germane plant life. Over-exploitation of forest resources has affected plant diversity and various species have been forced to go into extermination. Thus, it is imperative to protect and preserve the vegetative species which supports life and the functioning of our ecosystems. Botanical gardens' strength and experience in conservation stem from their in-depth perception and understanding of the tutelage, management, and biology of a wide range of plant species. Ex situ and in situ conservation projects aiming at safeguarding endangered species, rebuilding imperilled populations, and maintaining living plant and seed collections of endangered species are some of the ways of improving the existence of botanical gardens. Improving the existence and impact of botanical gardens is tantamount to sustenance of vegetative species all over the world. The advent of greenhouse system in plant production has stimulated the production of plants, thereby avoiding extinction which may occur in the wild. With these immeasurable benefits, the production is

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affected by cost because plants need to be given full attention in terms of water and nutrient supply for optimal production. The greenhouse system of gardening is a fast-growing system which involves the production in a controlled environment. This measure has generated an increase in production per unit area based on the aim of the farmer and availability all year-round. This book chapter therefore describes the concept of botanical gardens, its economic importance, challenges, and potential strategies to be employed for sustainability.

Keywords Botanical garden · Vegetative species conservation · Controlled system · Greenhouse technology · Plant biodiversity

3.1 Introduction

The loss of plant diversity in the world today is at an unprecedented rate; this is due to various threat factors such as forestry activities, pollution, environmental degradation, land use, globalization, and climate change, which may lead to extinction of plant species and a decrease in services rendered by the ecosystem (Chen and Sun 2018). Plants have the power to enrich and sustain life, but they remain vulnerable to the effects of climate change as well as anthropogenic activities threatening their very existence. At present, the planet faces a potential loss of thousands of threatened species. While our activities continue to degrade and deplete the natural resources that are essential to our survival, we must remember that we derive direct benefits and advantages from these resources, and only sustainable utilization and long-term conservation can ensure that they are preserved for future generations.

The threats of extinction make plant conservation efforts very important in addressing the issue of sustenance of vegetative species. Promoting education and awareness of these threats is paramount in combating them. Development has led to increased fragmentation of natural habitats and significant increase in extinction rates. Over-exploitation of forest resources, in particular, has affected plant diversity and various species have been forced to go into extinction. It is imperative to preserve and protect vegetative species which bring life and support the functioning of our ecosystems and botanical gardens play an important role in the conservation of diverse plants species. There is a need to devote more resources and effort to the conservation of threatened species around the world while striking a balance between tropical and temperate plants. Botanical gardens are places where plant species are studied and conserved; they play an important role in meeting human needs which are enormous. In science, botanical gardens are useful tools in propagation, taxonomy, seed science, genetics, biotechnology, education, ecology, etc. (Donaldson 2009). They can also serve as a measure for biosecurity because they contain diverse native and exotic plant species (Wondafrash et al. 2019). In the world today, there are over 2500 botanical gardens (Golding et al. 2010) which house over six million plants and represent about 80,000 taxa which is equivalent to one quarter of vascular plants identified in the world today (O'Donnell and Sharrock 2017). It was reported that the Global Strategy for Plant Conservation (GSPC) have conserved

about 70% of threatened plants in botanical gardens (Huang 2018). There is still a dire need to conserve plant species most especially the ones in the wild. Gardens can preserve plant species for human consumption, use, and well-being and this function is very important in the increasing climatic change scenario which is becoming more severe (Dunn 2017; Ren and Duan 2017).

Climate change has caused a rapid increase in species extinction and, given the present trends, this situation is projected to get worse (Urban 2015). In 2002, United Nations Convention (UNC) on Biological Diversity (CBD) adopted a GSPC aimed at slowing the rate of plants extinctions by 2010. This decrease in extinction rate was proposed to be achieved through a strategy of five objectives. One of the targets was to have a working rundown of all established plant species to achieve the objective of understanding plant diversity through observation and documentation. This would serve as a key step in assessing the conservation status of the said plant species as such as a vital instrument in guiding conservation actions. Other series of action-oriented agreements reached by the GSPC to initiate urgent intervention and effective management of the extinction crisis include securing ecological regions through effective management and restoration, protecting plant genetic diversity, conserving threatened plant species in situ, ensuring plants in ex situ collections are available when needed for recovery and restoration programmes, and also preserving associated indigenous knowledge and local innovations while at conservation efforts. This chapter discusses extensively the concept of botanical gardens, and their role in conserving biodiversity of vegetative species.

3.2 History of Botanical Gardens

The concept of gardening majorly focuses on conservation, but there are few reports on the species diversity of botanical gardens. It is important to relate the living collections of species richness pattern with the world's botanical gardens in the natural environment. This can be made possible by funding studies relating to botanical gardens so as to provide a plant database for future studies and monitoring of environmental factors (Sun 2016). Researchers on garden horticulture should stimulate collaboration with others in the field of systematics, genetics, and environmental studies so as to debunk the reports on the neglect of research in these field despite its positive contribution to the environment (Blackmore et al. 2011).

The universal need of man across the globe which is drugs and spices has been reported to be the basis of botanical gardens, with the need of plants as spices in the tropics and as drugs in Europe necessitated the establishment of botanical gardens in these regions. The history can be traced to the Aristotle's Garden at Athens (Greene 1909), but evidences of garden formations were reported in Egypt, Assyria, China, and Mexico which cultivated plants in their gardens for economic or aesthetic purposes. The earliest garden was the Royal Garden of Thotmes III in year 1000 B.C. and was planned by the head gardener Nekht who was attached to the Temple of Karnak (Holmes 1906). The Chinese may be attributed as the real

founders of gardens and the plants grown at that time were for economical and medicinal values. These plants were tested by the Father of Medicine and Husbandry, the semi-mythical Emperor Shen Nung of the twenty-eighth century B.C., and reported the plants cure diseases. The interest in study and learning about plants increased from the fourteenth and fifteenth centuries, their uses, and information about plants increased. The botanical garden at Edinburgh has evolved and presently is the sixth and only garden left in the Scottish capital despite three gardens being identified in the eighteenth century.

Botanical gardens with known established date are up to a total of 1594, among which 54% were confirmed during 1951 and 2001. The progressive report for creating emerging botanical gardens in various parts of the world shows no declining signs till date. For the last 50 years, botanical gardens have emerged in almost all regions across the world, most especially in the topics. For a mention, in Brazil, out of 29 botanical gardens known in the region, only two are investigated to be established earlier than 1900, but at least 14 gardens have been established since 1990. There are still comparably few botanical gardens around the world, like the Middle East, China, and Asia, among others in the late 1990s, while various new botanical gardens and projects were initiated, and existing ones rehabilitated.

3.3 Biological Diversity of Plants

The diversity of plants species around the world is a topic of interest for many plants' specialists and scientists as biodiversity, in itself, is the fundamental basis for the sustainability of mankind (Chen et al. 2017) Biodiversity, which derives from the words 'biological' and 'diversity', consists of three major aspects, including diversity of genes, species, and ecosystems. It encompasses 'the assortment of living things found at all sizes of natural association, going from qualities to species to biological systems' (eAtlas.com). Genetic change and evolutionary processes are among the factors responsible for an increase in biodiversity while a reduction in diversity is usually caused by habitat fragmentation and destruction, as well as various climatic impacts on the environment. The level of biodiversity existing on the planet earth helps ecosystems achieve stability and presents an important influence on the resilience of ecosystems to certain disturbances. Plants create the habitat for many ecosystems and at the same time play an important role in the stabilization of the soil system while inhibiting erosion.

Plants make up a huge part of global biodiversity and serve to provide the major nutrient sources to food webs as well as provide shelters to animals. The network of operations within a functioning ecosystem is such that when a plant species is lost, either due to over-collection of that species or its outright destruction and phasing out, a destabilization, however, slightly occurs in the ecosystems. Other species, plants, and animals alike rely on the lost species for any kind of relationship or interaction, which may negatively affect them. These negative impacts may come in the form of loss of food source or shelter. Also, the loss of a species may mean the

loss of a natural resource needed for medicine, fuel, or food. Biodiversity loss is, therefore, a major threat not only to the planet but its inhabitants as well.

Consequently, it is important to carry out plant conservation activities to continue to enjoy the benefits and functions of existing biodiversity. Intentional preservation of diversity, as well as sustainable use of plant resources, is crucial for preventing biodiversity loss.

3.4 Conservation of Biodiversity in Botanical Gardens

The aim of conservation is to promote the management, preservation, and restoration of biological diversity. Since plants are vital to life, plant conservation is a key aspect of biological conservation as it aims to conserve whole ecosystems and associated habitats in the actual sense. Plant conservation activities require the cooperation of everyone to ensure the preservation of native plants communities and habitats around the world.

Conservation is a major activity in both the educational and research programmes of botanic garden. The various measures for conservation of plant diversity include internal and external conservation, direct ecological intervention, reinforcement and reintroduction, and assisted migration (Wyse Jackson and Kennedy 2009). In the saving of biodiversity, botanical gardens play an important role and have great potentials for doing more for the future of biodiversity, especially that of plants (Heywood 2011). Botanical gardens engage in the study and conservation of several vegetative species both ex situ and in situ.

3.4.1 In Situ/Internal Conservation

Botanical gardens are largely recognized for the role they play in ex situ conservation of plants, but their in situ conservation activities which are imperative are often overlooked (Chen et al. 2009; Mammides et al. 2016). In situ conservation is the keeping of plants in their natural habitat for the purpose of protecting and studying them. In situ conservation areas include areas where plants are monitored, preserved, and managed in their native setting and these commonly include botanical gardens. Botanical gardens in the tropical environment is meant to have a positive role to play in situ conservation. This can be achieved through the direct promotion of initiatives such as the reintroduction of valuable native species, habitat restoration, 'assisted migration' of species that are vulnerable to climate change, as well as a creative collaboration with both governmental and non-governmental agencies, and the local people or communities. (Chen et al. 2009).

3.4.2 *Ex Situ Conservation*

Another method for preserving vegetative species is the protection and management of biological diversity outside of their native or natural habitats. This is referred to as ex situ conservation. Ex situ conservation efforts are usually aimed at protecting endangered plant or animal species by removing part of the population from the pressurized habitat to locate them in another area that could be under the care of people or in a wild setting. A setting under the management of humans is typically preferred for the conservation of threatened species. Storing or growing different plant species away from their native habitat is a way of protecting plants for the future, especially when their original habitat is endangered. Up to 30% of the world's plant species are comfiture outside of their original ecosystem in botanical gardens around the world (Mounce et al. 2017). It is therefore indisputable that botanical gardens serve a key function in the preservation and management of endangered species. Although vegetative or seed propagation is oftentimes easy and cheap, management of ex situ plants is more expensive than in situ.

3.5 Role of Botanical Gardens in Sustainability of Vegetative Species

Botanical gardens typically consist of a fairly wide variety of plant species that are identified and labelled with their local and scientific names, and occasionally, their taxonomy and unique characteristics. There are different types of botanical gardens, each with different plant varieties, such as trees, shrubs, flowering plants, and even herbs. Many of the varieties contained in botanical gardens are from specific parts of the world. Some plants may be tropical while others are temperate. Greenhouse technology may be employed for the preservation of species less suited for an environment in an ex situ conservation programme. When a species is at risk of been endangered in the wild, the ex situ method of conservation becomes a viable means of ensuring its survival.

Mounce et al. (2017) concluded that botanical gardens conserve plant diversity ex situ and can prevent extinction through integrated conservation action. In their research, they enumerated how diversity is conserved in botanical gardens across the world. According to them, 105,634 plant species are managed in botanical gardens. This amounts to about 30% of all studied plant species. Over 41% of known threatened species are also said to be conserved. However, the botanical gardens under their study were disproportionately temperate, leaving about 76% of species of tropical origin absent from their collection. Due to phylogenetic bias, there exists a disparity between the percentage of vascular genera and non-vascular genera that is conserved ex situ. Botanical gardens, however, continue to respond to the threat of species extinction even though a little capacity of them is devoted to threatened species.

3.5.1 Ecological Restoration

A good percentage of plants conserved ex situ are to be made available for species restoration and rehabilitation as well as research endeavours. Researchers can collect rare plants in botanical gardens to investigate the methods of plant conversation in natural habitats. Also, the exploration of plants aimed at recognition of threats and timely intervention efforts for species in danger of extinction is another related role of botanical gardens. Ecological restoration focuses on ensuring the resilience of native plant species and diversity in restored or protected areas, and on the establishment of reserves.

3.5.2 Botanical Gardens' Role in Urban Greening

The complications of conservation and development are twisted. Inferably, in tackling one, the other should also be considered. The challenge of poor environmental quality is an issue with many developing countries while some city areas in developed countries are not left out too. The Greening projects aimed at improving the outlook of neighbourhoods have been conducted by functioning botanical gardens. For instance, in Russia, some botanical gardens have focused mainly on developing new strains of plants that can withstand harsh climate condition. In the same vein, New York Botanical Garden also laboured to transform derelict lots into a safe abode by working with individuals and community groups in Bronx (Keller 1996). One of the important roles of botanical gardens in plant conservation is the cultivation and horticulture aspects, while they also maintain plant genetic diversity ex situ. Botanical gardens, therefore, remains a powerful resource for plant conservation programmes.

3.5.3 Role of Botanical Gardens in Scientific Research

The scientific contribution of botanical gardens in terms of research in plant science and horticulture remains one of the major advantage botanical gardens present. The living collections of plants in situ and ex situ conservation method endeavours not only help preserve genetic diversity but also support several activities in research and development. There are questions about biological diversity and a wealth of information to be garnered on the genetic level through works in scientific research. Resilience and adaptability of plants, resistance to pests, and diseases are examples of knowledge that can be sourced on the level of genetic diversity. Scientific research helps us understand biodiversity on both ecosystem and genetic levels to improve our interpretation of the diversity of nature. Botanical gardens are used to preserve seeds or germplasms of plants for easy access for upcoming research, utilization, and

or propagation. This process which involves careful seed collection and storage is known as seed banking and is a method of ex situ conservation that helps protect a species of plant and minimize its risk of extinction.

Through research and scientific experiments, botanical gardens can be a platform for the generation of plants that can be of environmental benefit or economic importance to the society. Botanical garden researchers, using their knowledge of plants characteristics, can also invest their expertise to improve upon the existing approaches to maintain and preserve endangered species, and to investigate alternative methods of plant conservation in their natural environment.

According to Donaldson (2009), global change in research depends on the opportunities botanic gardens brings due to the gathering of living collections of species involved. It is also believed that it has a role in bridging the gap between conservation of biological diversity and the benefits from the ecosystem services. Botanic gardens and scientific institutions should, therefore, be strengthened to support more research and development activities and to ensure that the preservation of genetic diversity is at the maximum level possible and endangered vegetative species are well conserved. For the overall well-being and sustainability of vegetative species on a healthy planet, scientific contribution to botanical gardens should be intensified and strengthened for better conservation of biological diversity.

3.5.4 Recreation and Well-Being of Humans

Contemporary policies for conservation, such as the Convention on Biological Diversity (CBD) and the GSPC, judge it important that human needs be taken into account in conservation (Glowka et al. 1994). Botanical gardens are a popular place for visitors. Per annum, hundreds of millions of people visit the over 2000 botanical gardens holding about 80,000 plant species in their living collection (Wyse Jackson 2001). Botanical gardens remains a strong force of attraction throughout the world to date as they provide a wonderful visual representation of the beauty of nature coupled with immense value for plants. The role botanical gardens serve in terms of recreation cannot also be underemphasized. They not only conserve and promote indigenous plant knowledge but are appreciated for their aesthetic beauty and offer a range of other social benefits. Plants are key to the well-being of man and his environment as they are responsible for the release of oxygen into the atmosphere, and the absorption of atmospheric carbon dioxide during the photosynthesis process. They also serve as a source of food, spices, and medicine. It is from plants we derive ornamentals and herbs, as well as cash crops, and fruits. Man can live in health, well-being, and prosperity due to the existence of vegetation.

The extensive resources and huge expertise available at botanical gardens see to the ability of these gardens to contribute to human well-being. Usually, the stores of knowledge accrued from years of plant collection, taxonomy research, and seed banking afford the opportunity to develop useful plant medicine as well as to conduct researches into specific properties and uses of plants and their various

parts. The Botanical and Experimental Garden of Radboud University, the Netherlands, investigated the taxonomy, morphology, nutritional qualities, and alkaloid properties of African Solanum which are commonly consumed as leafy vegetables and herbs by African consumers to provide a definite and comprehensive 'safe to eat' guide. Also, Kisantu Botanic Garden in the Democratic Republic of Congo conducted experiments on a particular fruit, 'mangosteen', with the sole aim of discovering how to extend its shelf life to reach a larger market (Kibungu Kemelo 2004).

Many botanic gardens are engaged in the cultivation and evaluation of traditional medicinal plants to establish a system of medicine that is sustainable and meets local needs. Improvement in both health and nutrition through home gardening endeavours can also be observed in local communities that have been educated and empowered in the creation of home gardens and the use of novel plants. Hence, botanical gardens contribute significantly to human well-being especially by promoting access to food and medicinal plants for proper nutrition and health care. There have also been claims of gardens playing a role in the development and hosting of horticultural therapy techniques for the treatment of mental health problems which, according to the World Health Organization, is universally widespread. Botanical gardens and the conservation of biological diversity, thus, can be linked with improvements in the well-being of humans.

3.5.5 Botanical Gardens and Biosecurity

Globally, plant health is affected as a result of invasive pests and pathogens which can cause significant loss on ecological and economic damage (Lovett et al. 2016). In the Unites States alone, these invasive pests were reported to cause damage up to 39 billion dollars per year (Pratt et al. 2017) and these pests have increased over the last decades in many countries (Wingfield et al. 2015; Hurley et al. 2016). These increases have been attributed to trade, travels and the movement of live plants form one location to another (Santini et al. 2013). Measures of quarantine have been posed so as to reduce the spread, but the lack of knowledge on novel pests and pressures from predation and parasitism can make the natural environment complex. To this end, information on the invasive pests is unknown to science because their identification and mode of action are new to science, prior to their occurrence in the new environment.

The major target of botanical gardens and biosecurity is the issue of pest detection and management. Wondafrash et al. (2019) identified various hazards as well as opportunities presented by gardens as bridgeheads for invasions, sentinel sites for pest detection, and eradication for research, and for various meaningful engagements regarding biosecurity issues.

3.5.6 Gardens as Bridgeheads for Invasions of Pests

From time immemorial, botanical gardens have historically been identified as areas for conduits in the introduction of plants (Hulme 2011). It is evident that despite the role of conservation played by gardens, it poses high risk if introduction of pests (Liebhold et al. 2012). Therefore, the gardens can be pictured as a pathway of introducing pests and the activities in the gardens can establish their spread to the surrounding environment. For instance, the invasion of the root rot fungus (*Armillaria mellea)* in South Africa as reported by Coetzee et al. (2001, 2003). It was initially detected in two locations: Company's Garden and Kirstenbosch National Botanical Garden and now it was reported by Coetzee et al. (2018) that the pest was found in the natural vegetation surrounding the Table Mountain National Park which is a UNESCO world heritage site. With the pests already established at the Kirstenbosch Garden in South Africa, plants were donated to London which resulted in an accidental introduction of the five sap-sucking hemipteran pests (Salisbury et al. 2011). These were resolved by quarantine measures and there is dare need for this activity coupled with repeated inspections.

3.5.7 Gardens as Sentinel Sites for Detection and Elimination of Pests

Emerging research into sentinel plants has enabled emerging pest risks to be detected and identified. Projects, such as the European Horizon 2020 Holistic Management of Emerging Forest Pests and Diseases and the IPSN, are basically into sentinel plant research in the world today (Hulbert et al. 2019). A report showed that 67 pest species were detected in South Africa alone from different gardens from 1996 to 2019 (Tchotet Tchoumi et al. 2019). Recently, Mansfield et al. (2019) reported several novel pest–host associations between bacteria, fungi, insects, and nematodes from sentinel plants and botanical gardens. When these detection and identification of pests are prompt, eradication is much easier, thereby reducing all forms of risks to the natural environment, vegetation, and agricultural production systems (Kenis et al. 2019). Eradication of established pathogens in the natural environment is very difficult, but there have been reports of successful eradication from controlled environments (Paap et al. 2020); therefore, early detection and identification of pest is easier to achieve in botanical gardens when compared with the natural environment.

3.5.8 Determination of Pest–Host Range

A variety of plants in gardens are useful in determination of pest–host ranges and can infer information on the future threats of such hosts on plant health (Scott-Brown et al. 2018). In the case of presence of exotic plants, it can provide information on the possible threats, thereby stimulating regulations and possible quarantine measures against pests (Groenteman et al. 2015). Such studies were conducted on *Euwallacea fornicates* in the Los Angeles Arboretum in California (Eskalen et al. 2013) and it reported the potential of beetles and its fungal symbiont to establish in diverse plant communities in the United States and beyond. This method has been introduced in South Africa. Studies were also conducted on *Xylella fastidiosa* which dwells in the xylem and causes different diseases in plants.

3.5.9 Public Awareness and Education

To enable people to improve their lives through environmental education, the expertise of botanical gardens cannot be brushed aside (Willison 2006). An example of the role botanical gardens play in public awareness can be found in Uganda. Using various methods of communication to transfer knowledge and skills, the Botanic Garden at Makere University educated groups of women and children on the usefulness and cultivation of certain medicinal plant species (C. Kiwuka, survey response).

It is crucial to promote the importance of plant conservation to the public and botanical gardens help in this regard. They increase public understanding and awareness of threats to plant diversity as well as promote education on biological conservation and how this helps prevent biodiversity loss, achieve sustainability, and prevent the extinction of key plant life.

Botanical gardens are sometimes involved in local conservation efforts through education, training, and capacity building. This helps in the sourcing, documentation, and preservation of local and indigenous knowledge on plant conservation. When botanical gardens, in turn, disseminate to the public both the cultural knowledge garnered on local levels and the scientific knowledge from research on plants, the required public awareness and education on plant conservation can be effectively achieved.

3.6 Highlights of Existing and Functioning Botanical Gardens

Botanical gardens are being managed by different organizations and administrations. They are managed either by the state or by regional or local authorities. The universities and other research institutes own over 30% of the world's botanic gardens while a relatively small proportion are private owned.

Recently, for botanical gardens to improve functionality, operations should be guided to achieve more financial and independence in administration via independent fund-raising efforts. The various categories of botanical gardens are presented in Table 3.1.

3.6.1 Regional Distribution of Botanical Gardens

In Western Europe, France, Germany, Italy, and the UK have the greatest number of botanical gardens while only Greece has a relatively small number of botanical gardens which are mostly minute institutions/organizations. The largest number of botanical gardens in the East and Central Europe are found in the Czech Republic and Poland (Table 3.2). Majority of the botanical gardens are located in Australia and New Zealand while relatively few are in the Pacific Ocean Islands. The categories of the global botanical gardens were also stated by Wyse Jackson and Sutherland (2000). Similarly, some countries do not possess botanical gardens, for example, The Cook Islands, Polynesia, Guam, Kiribati, Marshall Islands, Micronesia, Nauru, New Caledonia, Palau, Pitcairn, French, Islands, Saipan and Tinian, Tonga, U.-S. Pacific Trust Territories, Tuvalu, and Vanuatu. The countries in the South-West Asia and Middle East have smaller of botanical gardens, though there are no botanical gardens in Afghanistan, Bahrain, Jordan, Lebanon, Qatar, Syria, and Yemen.

3.6.2 Report on Distribution of Botanic Garden Worldwide

The world according to BGCI database (2000) stated that a total of 2178 botanical gardens are known to be existing and distributed around the world. The highest (878) been recorded from Europe while the least is from Africa. However, some regions do not have botanic gardens. Africa has 127 botanical gardens with the highest (60) from the West, Central, and East Africa which was closely followed by Southern Africa (38) and North Africa (20) while Indian Ocean Islands have the least (9). In America, a total of 617 botanical gardens are recorded with the least (38) from the Caribbean Islands, and the highest 355 from North America while others 122 from South America and 102 from North America. In Asia, the East and

Table 3.1 Categories of botanical garden

Type	Activities/purpose
Classic multi-purpose gardens	For improving training in horticulture and horticultural related studies. It also helps in research particularly ones associated with botany, taxonomy. For effective result, herbaria and relevant laboratories should be associated with. It also serves as a means of educating the public and as amenity for the populace
Gardens of ornamental plants	These are mainly used for penning down different plant collections; it also plays important role in research, educating the populace, or conserving the species to avoid extinction
Gardens meant to value history	They are established to improve the teaching of medical related courses; some were established for religious purposes which focus majorly on the gathering and production of medicinal and herbs plants, also to assist in increasing the awareness of the public on the cultivated plant species
Gardens solely for conservation	This is established for developing the major need of the community which are solely plant species conservation. Some communities possess natural vegetation in addition to their natural environment. Also, this garden type conserves indigenous garden plants, cultivated only from within and outside their region and overall flora. Most conservation gardens are useful tool in training and educating the public
Gardens meant for both botany and zoology	This is established to collect plants which are being evaluated, experimented, tested, and developed to provide habitats for the displayed and available fauna. In addition, botany gardens provide interpretation of these habitats for public consumption which is also an important element in biological conservation and observation
Gardens created in the university	As the name implies, it is mainly for teaching and research; other functions may include recreation, improve well-being of the university family and environs
Gardens for the purpose of Agriculture, botany, and for keeping germplasm	It functions as a plant collection outside the ecosystem. It has high economic value prospective for conserving, exploration, plant pedigree, and improvement and agriculture. Most of them are preliminary experimental stations which are associated with Institutes of agriculture or forestry while teaming with other synonymous laboratory in plant improvement and seed testing which may not open for public consumption
Gardens located on Alpine or mountain	They are mostly found in regions with mountains in Europe and other Tropical countries. They are designed particularly for the production of mountainous and alpine flora, and or in the case of tropical

(continued)

Table 3.1 (continued)

Type	Activities/purpose
	countries, for the cultivation and reproduction of sub-tropical or temperate flora. Some gardens located on alpine and mountains are secondary gardens
Gardens for keeping indigenous and wild species	This type of garden is regarded as a vegetative area, natural or semi- natural, which is enclosed and well managed. Most of this type of garden are created to play the role of conserving species and for educating the public especially in areas where a specific native and indigenous plants are grown and known
Gardens for horticultural purpose	They are private owned and managed by horticultural societies and organizations, thus available and accessible to the general populace. They operate majorly to invite and improve the growth and development of horticulture through the training of professional gardeners and plant breeders and conserving different garden plant varieties and species
Thematic gardens	These gardens focus majorly on cultivating small range of morphologically comparable or similar plants and plants grown to illustrate a particular purpose mostly in support of education, science, research, conservation, and exhibition. These include orchids, rose plants, Rhododendron, bamboo, and succulent gardens or gardens established on such themes as ethnobotany, medicine, bonsai, topiary, butterfly gardens, carnivorous plants, and aquatics
Gardens for the community	These are generally small gardens owned by the community with little or no resources, which is created and developed for, and by, a local community to fulfil its special purpose and vision which may be either be recreation, education, conservation, training, and for the growth of medicinal and other economic plants

Southeast Asia has 220 botanical gardens; the Southern Asia has 143 while the Midian East and South West Asia has only 40. The region of Australasia and Oceania has just 153 botanical gardens. The Western Europe has 583 followed by Russia and the C.I.S. with 170 botanical gardens while Central and Eastern Europe has 125 making close to a total of 878 botanical gardens in Europe.

3.6.3 World Best Botanical Gardens

The most massive botanical garden around the globe is Kew Royal Garden in London. It is an international garden with research focus and educational institute mindset. The garden employs more than 1100 employees with a fascinating and

Table 3.2 Regions in the world with existing and functioning botanical gardens

Countries	Botanical gardens
West, Central, and East Africa	Nigeria has the highest number (16) of botanical garden in this region, followed by 9 in Kenya although most major countries have one or more. Countries like Guinea, Burkina Faso, Equatorial Guinea, Guinea-Bissau, Sao Tome, Congo, and Principe have no botanical gardens
Southern Africa and the Southern Atlantic Islands	South Africa possesses the highest number of botanical gardens in this region. Recently, new botanical gardens have been established and extended to several countries. Ascension Island and South Georgia have no botanical gardens
Southern Asia	Every country in the Southern part of Asia has a botanical gardens, although the largest achievement and establishment are in India. Recently, Bhutan has her pioneer botanic garden established
The Caribbean Islands	The highest figure of botanical gardens is in Cuba. Many of the newly established and developed institutions focused majorly on conservation and increasing knowledge of biological diversity. Major island countries have at least one botanical garden, though some may generally be either old and historical gardens or relatively recently established. There are no botanical gardens recorded in the following countries: Haiti, St Lucia, and the Turks and Caicos
South America	Argentina, Brazil, and Colombia have almost all the botanical gardens in this region. However, many of these gardens have just been established particularly in Brazil and Colombia
East and Southeast Asia	Most of the botanical gardens in these regions are located in China where there are over 100 with Japan having more than 50. There are no known botanical gardens in Brunei Darussalam, Cambodia, and the Lao People's Democratic Republic
Central and North America	A majority of botanic gardens in these regions exist in the United States, Mexico, and Canada. All Central American countries have at least one botanical garden.
Indian Ocean Islands	Botanical gardens exist in 4 territories of the Indian Ocean Island and countries like the Seychelles, Mauritius (where the oldest tropical botanical garden in the world exists), Réunion, and Madagascar. There is no botanical gardens in the British Indian Ocean Territory, the Maldives, Comoros, Mayotte, or Rodrigues
North Africa	This region has few botanical gardens which are scattered throughout the area, other than in Central African Republic, Chad, Djibouti, Eritrea, Mali, Mauritania, Niger, and Somalia where none is established. There are developments and expansion in countries like Morocco and Tunisia

beautiful environment (Table 3.3). There are other large botanical gardens available all over the world and India. Although Kew Royal garden is the largest botanical garden, there are many other interesting botanical gardens as well in the world and must be visited, with details stated in Table 3.3.

Table 3.3 List of the world best botanical gardens in the world

S/N	Botanical garden	Year established	Acre	Location
1	Kew Royal	1840	320acre	London, UK
2	Longwood Gardens		1000 m^2	Philadelphia, USA
3	Jardin Botanique Montreal	1931		Canada
4	Hawaii Tropical	1984	17acre	USA
5	Orto botanico di padova	1542	22,000 m^2	Italy
6	Botanischer Garten	1809	18acre	Munich
7	Kirstenbosch Botanical		89acre	South Africa
8	Singapore Botanical	1859	183acre	Singapore
9	Sydney Royal Botanical	1816		Australia
10	New York Botanical		37acre	United Kingdom

Table 3.4 Botanical gardens in Africa

S/N	Botanical garden	Location
1	Kirstenbosch National	Kirstenbosch, eastern Cape Town
2	Mauritius National	Pamplemousse, Mauritius
3	Jardin Majorelle	Marrakech, Morocco
4	Aburi	Accra, Ghana
5	Sarius Palmetum	Abuja, Nigeria
6	Nairobi	Nairobi, Kenya
7	Jardim Tunduru	Maputo, Mozambique
8	Entebbe	Lake Victoria in Entebbe, Kampala.
9	Seychelles National	Outskirts of Victoria on Mont Fleuri
10	Aswan	Egypt

3.6.4 Exquisite Botanical Gardens in Africa

Gardens are haven for various flora and fauna diversities offering conservation of these species with educational and recreational functions. Listed below are some exquisite gardens in Africa as described by Africa.com (2019) (Table 3.4):

- Kirstenbosch National Botanical Garden
- Jardin Majorelle Botanical Garden
- Mauritius National Botanical Garden
- Seychelles National Botanical Gardens
- Aswan Botanical Garden
- Entebbe Botanical Garden
- Aburi Botanical Garden
- Jardim Tunduru Botanical Garden
- Sarius Palmetum Botanical Garden
- Nairobi Botanical Garden

3.6.5 Description of the Listed Botanical Gardens

Kirstenbosch National Botanical Garden It was established in 1913 to preserve flora diversity in Kirstenbosch, Eastern Cape Town's Table Mountain. It is the home of the country's national flower, the Protea, and others, like Fynbos, Erica, and Restios and houses over 125 bird species, insects, and amphibians.

Jardin Majorelle It is located in Marrakech, Morocco in 1886 by Jacques Majorelle who was a French painter and purchased in 1980 by two French designer partners: Yves Saint Laurent and Pierre Berge. It houses about 30 species of cactus family, bamboos, and variety of bird species, such as sparrows and turtledoves. The garden has a monument erected in 2008 and a Berber Museum opened in 2011 which contains the historical background of the Berber tribe.

Mauritius National Botanical Garden It is located in Pamplemousses, Mauritius and formally known as Sir Seewoosagur Botanical Garden. It is the most visited on island and was initially the private garden of the French governor almost 300 years ago but was launched as the country's botanical garden. It houses over 600 species of plants, talipot palm trees, jackfruit tree, and Indian almond tree.

Seychelles National Botanical Gardens It is located outskirts of Victoria on Mont Fleuri and houses diverse flora and fauna; Koko Maron which is used to make brooms and ropes by natives; and Coco Der Mer which is the largest nut in the plant kingdom. The garden has a signature feature of brightly coloured orchid house with variety of orchids and native orchids.

Aswan Botanical Garden This is a world class garden located in the heart of Egypt on an island in River Nile as Aswan, similarly known as the Kitchener's Island or El Nabatat Island and was owned previously by Lord Kitchener in 1800s. It leisure spot and area for botanical research is located in Egypt. It contains rare and exotic species of plants and wildlife.

Entebbe Botanical Garden It is located along the shores of Lake Victoria in Entebbe, Kampala. It contains a large extent of different birds like eagle owls and weavers and wildlife birds, like the yellow-bellied duck and grey-headed gull. Apart from these, it houses a small rainforest which contains medicinal plants, tall trees, and a thick forest of bamboo.

Aburi Botanical Garden It is listed among the most beautiful gardens of tourist attraction outside Accra coastal plain, Ghana. The garden encourages cocoa production by supplying seedlings and scientific information to the southerners, Ghana. It houses several flora species for conservation, like the Ficus tree and medicinal plants. There are diverse birds and butterfly species for nature lovers.

Sarius Palmetum Botanical Garden It is located in Abuja, Nigeria, and houses over 1000 different plant species and 450 palm species. It houses several flora species, Nigeria's oil and coconut palm, golden and royal palms, and endangered

plants, like pepper fruit, sea grapes, and cherry. The garden was created with the aim to conserve Nigerian indigenous plants by a plant lover called Aisha Mohammed.

Jardim Tunduru This is a beautiful garden located in Maputo which is the heart of Mozambique's capital. It was rehabilitated and reopened in 2015 with addition of greenhouse, fences, public benches, and improved irrigation and sanitation systems. It houses a rich collection of flowers, trees, and shrubs such as magnolia and Palmae plants. It also houses birds, butterflies, and colony of bats which utilizes the trees as haven.

Nairobi Botanical Garden This is a beautiful garden in Nairobi Museum and ideal for picnics and relaxation in Kenya. It is the home of 600 indigenous and 100 exotic species of plants for research, education, and conservation. It also displays the herb garden which contains the indigenous medicinal plants, the papyrus plants, water lilies, and other aquatic plants.

3.6.6 Categories of Worldwide Botanical Garden Ex Situ Collections

The highlights below are a broad category representing the worldwide collection of ex situ botanical garden.

- *Limited collections*
  - Rock garden plants and Alpines
  - Herb/spice plants species
  - Bonsai
  - Bulbs
  - Carnivorous plants species
  - Medicinal/herb plants
  - Ornamental plants
  - Scanty and endangered plants
  - Temperate region fruits
  - Temperate region herbaceous (perennials)
  - Temperate region (trees, shrubs, and climbers)
  - Tropical region fruit trees
  - Tropical region timber trees
  - Tropical region flowering and ornamental plants
  - Wild crop species
  - Xerophytes species
- *Taxonomic collections*
  - Woody plants
  - Aroids

  - Bromeliads
  - Cacti
  - Conifers
  - Crassulaceae
  - Cycads
  - Euphorbiaceous
  - Ferns
  - Ficus
  - Grass
  - Bamboos
  - Legumes
  - Orchids
  - Palms
  - Rhododendrons
- *Collections based on geographical location*
  - Temperate indigenous plants in North America, Europe, and Asia
  - Temperate Woody indigenous plants in Australia, New Zealand, and South America
  - Plants of the Mediterranean regions of Europe, Southern Africa, South America, and Australia. Island plants
  - Collections from tropical continental South America, Southeast Asia and Africa and other countries with few numbers of botanic gardens.

3.7 Herbaria

A herbarium is a collection of non-living specimens of plant for scientific study. It is usually dried and mounted on a plain sheet of paper. Mostly, existing botanical gardens across the globe either contain and or are closely collaborating with a herbaria. Many harbour important, different, and indispensable scientific resources documenting the world's plant species diversity (BGCI database 2000). Historically, various original collections on which plant identity are based and enveloped in herbaria other than the natural habitat of the concerned species. For the sake methodology of science, strategy has to be established or planned to evaluate the need for herbaria, which is to allow accessibility to their plant collections. A point to note is the fact that most of species preserved in botanical gardens herbarium are vascular plants, few important specimens of non-vascular plants, like the bryophytes; several botanical gardens also preserve microorganisms. The major botanical garden herbaria are listed in Table 3.5.

Table 3.5 Herbaria in major botanical garden

Botanical garden	Location	Specimens (aprox.)
Museum National d'Histoire Naturelle	Paris, France	8,000,000
The Royal	Kew, U.K.	7,000,000
Conservatoire et Jardin Botaniques	Geneva, Switzerland	6,000,000
New York Garden	U.S.A.	5,600,000
Komarov Botanical Institute	St Petersburg, Russia	5,000,000
Missouri Garden	St Louis, U.S.A.	3,500,000
University, Jena	Germany	2,800,000
Helsinki, University	Finland	2,720,000
The Berlin Dahlem	Berlin	2,000,000
University, Uppsala	Sweden	2,000,000
Kebun Raya Bogor	Indonesia	2,000,000
Beijing Garden	China	2,400,000
University, Copenhagen	Denmark	2,500,000
Institute of Botany	Pruhonice, Czech Republic	2,000,000
Royal Garden	Edinburgh, U.K.	2,000,000
National Garden	Belgium	2,000,000
University of Tokyo	Japan	1,500,000
Indian Garden	Calcutta, India	1,500,000
Goteborg Garden	Sweden	1,350,000
University of Wien	Vienna, Austria	1,300,000
University of Oslo	Norway	1,300,000
Pretoria National	South Africa	1,200,000
Melbourne Garden	Australia	1,170,000
Sydney Garden	Australia	1,000,000

3.8 Major Challenges Facing Botanical Garden Existence in Africa

Mostly public and private botanical gardens, the major challenges reported have been the increased rate of using threatened and or wild species due to insufficient resources and opportunity for acquisition of species seeds (Bischoff et al. 2008; Brancalion et al. 2011). Others are insufficient knowledge of threatened species, lack of efficient propagation, and planting methods (Volis 2016). To resolve the challenge, seed availability must increase (Jalonen et al. 2017; Silva et al. 2016); a comprehensive list of existing species must be created to know which variety of species are available, necessary, and appropriate for their nursery site. Furthermore, other strategies include as follows:

- Seed sharing programme participation between private and public seed collectors, community-based, and local seed exchange programmes have been declared to increase restoration of biological diversity other than relying on any one strategy alone Brancalion et al. (2011).

- Seed obtaining support empowering nurseries to convey more species in satisfactory amounts closely.
- Increased information on compromised species so rebuilding professionals can settle on informed choices on which species they can certainly add without discouraging the situation rates.
- Increasing open doors for Ns and RPs to make partner networks where information, seeds, and scene level plans can be divided among entertainers.
- Use of long haul between situ and semi in situ protection systems, which all the while gives long haul conservation of hereditary variety and increment seed creation of target species. With an equilibrium of reasonable contemplations, it is feasible for reclamation plantings in the Araucaria timberland locale to be species rich, addressing an expanded number of useful gatherings and focused on the protection of the under-privileged plant species at the verge of extinction.

3.9 Way Forward on Improving the Botanical Garden Existence in Africa

Botanical gardens are important for the preservation and conservation of plant species like trees, shrubs, and flowers. Plants are important tools in promoting good health and social well-being among the people. They help achieve this by eliminating air contamination, decreasing pressure, empowering actual work, and advancing social ties within a community. It was reported that school kids with perspectives on trees are bound to dominate. Trees advance a solid economy and can give various assets to individuals. To reduce temperature, trees can be utilized. They also serve as habitat and food sources for animals.

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. Some of the ways of improving the existence of botanical gardens in Africa include the following:

Increased conservation: Botanical gardens are concerned with both in situ and ex situ conservation of plant species. Conservation can be done by both in situ and ex situ conservations.

In situ conservation: This is the conservation of biological components by enhancing their growth and survival in their home environment. This simply denotes that the growth and development of the trees are promoted in their locality where they normally occur in. This conservation type is concerned with the preservation of the ecosystem and the environment. This method has the added benefit of assisting in the continuing processes of evolution and adaptation within their habitats. Natural disasters such as drought, floods, and forest fires cause the species to adapt, and this strategy is highly cheap and convenient.

Ex situ conservation: According to the convention of Biological Diversity, it is the conservation of biological components outside their natural habitat. This means

the storage, propagation, and cultivation of plant or tree species outside of the locality they are primarily found. This kind of conservation has both positive and negative implications on the genetic composition of such plant species. The main purpose of a botanical garden is to facilitate ex situ conservation.

The techniques employed by botanical gardens for ex situ conservation of plant species are as follows:

Cryopreservation: This is done by storing the pollen, seed, or embryo under liquid nitrogen. Liquid nitrogen, a coolant produced from the fractional distillation of air, is made up of nitrogen in a liquid state. This method allows for almost endless storage of material without deterioration over a far longer time span.

Tissue cultivation: This is the cultivation of seeds or their propagative parts in test tubes, Petri, or culture dishes in a temperature- and light-controlled environment that promotes cell growth.

Field gene bank: A large-scale open-air planting used to preserve the genetic variety of wild, agricultural, or forestry plants. Field gene banks typically conserve species that are difficult or impossible to conserve in seed banks. Other ex situ procedures can also be employed to cultivate and select progeny of species maintained in field gene banks.

Ecosystem restoration: According to the United Nations Environment Programme (UNEP 2019), ecosystem restoration is 'a process of reversing the degradation of ecosystems, such as landscapes, lakes, and oceans to regain their ecological functionality; in other words, to improve the productivity and capacity of ecosystems to meet the particular need of society. This can be done by allowing the natural regeneration of over-exploited ecosystems or by planting trees and other plants'. Facilitating natural succession is an important part of ecosystem restoration. Human activities and obstructions frequently obstruct this process, necessitating solutions, such as removing exotic plants, minimizing soil erosion, and reinstalling native species to kick-start it. Ecosystem restoration aims to contribute to biodiversity conservation and sustainable use while also providing social, economic, and environmental benefits, with healthy and connected ecosystems helping to improve food and water security, people's livelihoods, and climate change mitigation and adaptation.

Maintenance of soil biodiversity: Soil biodiversity comprises the living components in the soil, like bacteria, fungi, termites, and nematodes. Soil biodiversity maintenance is important because the soil serves as the buffer for pests and diseases control, soil water, and structure determination as well as the availability of nutrients for the plants. Some of the methods of improving soil biodiversity are through the following:

Mulching: This is done by using materials, like polythene or grasses, to cover the soil surfaces. This reduces the rate of evaporation, thereby maintaining the soil water level. It also improves the availability of mineral nutrients in the soil and maintains soil temperature. This will increase the chances of survival of the different organisms residing in the soil.

Composting: A mixture of organic wastes, with or without soil, that has been allowed to decompose is used as an artificial manure to fertilize or enhance land.

Composting is an aerobic process (Schwedt 2001). Composting helps with fertilizing the crops, acting as a soil conditioner, increasing the humus content of the soil, and introducing helpful microbial colonies that help decrease the presence of diseases causing organisms in the soil.

Bulking soils from different places: Topsoil from an area with the desired biodiversity can be mixed together with the original soil of the place to introduce new organisms to the area.

Increased collaboration with other experts, like taxonomists, breeders, and horticulturists: There is a need for all hands to be on deck in the improvement of the botanical gardens all over. There is an urgent need to protect tropical forests, particularly lowland forests, in extensive nature reserves throughout all tropical countries, free of economic exploitation, such as logging, mining, hunting, and other activities. This can be achieved when all the stakeholders involved come together to promote botanical gardens.

Botanical gardens are key sources of plant ecology data, counting phenological signs of environmental change, plant physiology and plant development procedures, and plant–creature connections, as well as filling in as ordered and methodical study sites. All these are prerequisites needed for scientific research on health, pharmacology, as well as agriculture. The benefits associated with the development of botanic gardens to scientific research across all fields of work cannot be trifled with.

3.10 Greenhouse System of Gardening

With the ever increasing need to prevent the extinction of biological species especially in botanical gardens. Thus, there is increasing pressure on land especially for agricultural/food production/research/gardening especially in developing countries. On this note, there is need to adopt the new technology and innovation greenhouse brings that requires a little space with optimum result as reported by Timothy (2016). A greenhouse is a structure with controlled environment in which plants are raised and or grown for commercial and research. It can also serve as a means of keeping living plants to prevent extinction due to prevailing climate change among other challenges of sustaining biodiversity. Greenhouse structures are made from different covering (roof and wall) materials (glass or plastic) which are durable and lasts for up to 15 years. On an acre of land, close to 8 greenhouses can be erected depending on the intended use (Timothy 2016). The science behind the greenhouse technology lies between the fact that

1. The structure collects light and converts it to heat.
2. The greenhouse stores thermal energy and releases that energy properly.
3. It helps moderate temperature and produce a controlled environment for plants to grow and thrive optimally.
4. It also offers protection from wind, rain, snow, and other weather elements.

5. Finally engaging the greenhouse as a garden for conservation of biological species keeps the species from pests, animals and theft.

Greenhouse structures and practices are found in prestigious and magnificent botanical gardens and or gardens all over the world. Most of these gardens prefer the use of glass conservatories which serves dual purpose of practical/research and aesthetic/beauty. Conservatory and greenhouse are mostly interchanged, but specifically simple structures that functions mainly as a place for growing delicate or fragile plants and fruit trees.

On the other hand, conservatory doubles the activity of forms and functions. In conservatories, the plants are tendered intensively and shielded and equally camped in a bright glass structure; it can also serve the purpose of entertainment, refreshment, and/or relaxation.

The conservatory building is active all year-round with the advantage of producing refuge for outdoor plants and trees during the winter season, by providing adequate warmth and optimum access to sunlight. In the nineteenth century, greenhouse and/or conservatories structures are made from modern but energy efficient materials in which the present ones were used as background knowledge in establishing the trending gorgeous ones around the world, some of which are listed according to Leung (2016) as:

- The Curitiba Botanical Gardens, Curitiba, Brazil
- The Adelaide Botanical Garden, Adelaide, Australia
- The Brisbane Botanic Gardens Mount Coo-tha, Australia
- Gardens by the Bay, Singapore
- Botanique, Belgium, Brussels
- Belfast botanical garden, Ireland
- Botanical garden, Copenhagen, Denmark
- Goldengate Park, San Francisco
- Allen Garden, Toronto
- Muttart Greenhouse, Edmonton

3.11 Conclusion

The global diversity is incomplete without diversity in botanic plants which encompasses a huge part of the total diversity. Plants are a great source of highly nutritious food and doubles as abode for animals both large and small. Without adequate filing and recording of existing plant species, there will not be any way to trace the species which may be lost via over collection, destruction, climate change, and phasing out, among others. Humans are not left out in the plant species loss game as it means that a loss could lead to reduction in natural resources needed for medicine, energy, and food.

Efforts towards education are significant for botanical gardens to promote and implement various activities in plant conservation as communicating the importance

or significance of conservation is paramount for gaining the cooperation required to make considerable progress in achieving the goals of conservation. Availability of educational resources is one of the ways to educate the public and promote awareness on biodiversity and plant conservation.

In this vein, biodiversity loss is a major challenge for the ecosystem, planet, and its inhabitants. To avert the consequences, it is important to establish and evaluate existing plant conservation resources and structures to save the biological community and also to enjoy the benefits and functions of her existence. There has to be an intentional approach in the preservation of biological diversity coupled with sustainable use of plant resources. To prevent the influence of climate change, greenhouse conservatories are suggested; for phasing out species, updated recording is advised while the proper monitoring and administrative role must be independently controlled to facilitate growth and development of existing and upcoming botanical gardens.

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