

Plant Conservation in National Botanical Gardens of South Africa

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Abstract

The destruction of forests has led to plant diversity and species being lost at an unprecedented rate and a decrease in ecosystem services. Plant conservation strategies are important to support the development of livelihoods based on the sustainable uses of plants and promote the understanding and sharing of the benefits and functions of plants. Botanical gardens allocate most of their resources to plant conservation and the development of educational activities such as making plant species diversity known to the public. These gardens can also play an essential role in human well-being and provide in human needs. In this article, we review the history of the development of Kirstenbosch National Botanical Garden and the development of other national botanical gardens in South Africa. We will discuss conservation through cultivation, discovering and documenting diversity of plants, indigenous plants, threatened plants, medicinal plants, extinctions and rediscoveries, environmental education, conservation science, citizen science, horticulture, research and creating a haven for biodiversity. Future challenges and responsibilities of botanical gardens will be discussed including in situ and ex situ cultivation, promoting awareness, creating partnerships, increasing capacity building and training activities, sharing information and making gardens sustainable.

Keywords

Botanical Gardens, South Africa, Kirstenbosch, Plant Conservation, Plant Protection, Traditional Herb, Climate Change

1. Introduction and Background to Botanic Gardens in Plant Conservation

The destruction of forests has led to plant diversity and species being lost at an unprecedented rate and a decrease in ecosystem services. More than 100,000 plant

species face extinction due to habitat loss, invasive species, over-exploitation, environmental pollution, climate change and land-use changes. Efforts to develop integrative conservation approaches for the conservation of plant species are essential. Plant conservation strategies are important to support the development of livelihoods based on the sustainable uses of plants and promote the understanding and sharing of the benefits and functions of plants. Botanic gardens and their functions and role in society have grown over time.

The idea of “garden” dates to the Zhou dynasty in China, but the recent concept of a botanical garden started in Europe. The Padova Botanic Garden was built in 1545 in Italy (Chen & Sun, 2018). There are about 2500 botanical gardens worldwide (Golding et al., 2010) and these gardens are collections of plants cultivated in a closed area (Faraji & Karimi, 2020) and serve as places of biodiversity, culture and heritage, conservation, scientific inquiry and educating the public through displays (Willis, 2018). These gardens cultivate more than 6 million accessions of living plants, representing more than 80,000 taxa or representing about one-quarter of all the vascular plant species in the world (Jackson, 2001; O’Donnell & Sharrock, 2017). Botanic gardens play a significant role in the ex situ conservation and study of global plant biodiversity (Mounce, Smith, & Brockington, 2017).

One of the aims of the Global Strategy for Plant Conservation (GSPC) is to have 70% of the world’s threatened plant species conserved ex situ (Callmander, Schatz, & Lowry, 2005; Sharrock & Jones, 2009). Botanical gardens play a significant role in the preservation of medicinal plant species necessary for human health (Dunn, 2017), and this function of the gardens will become increasingly important as climate change becomes more serious (Ren & Duan, 2017).

Botanical gardens conduct several scientific activities such as conservation, propagation, horticulture, seed science, taxonomy, systematics, genetics, biotechnology, education and much more. The destruction of forests has led to plant diversity and species being lost at an unprecedented rate and a decrease in ecosystem services. More than 100,000 plant species face extinction due to habitat loss, invasive species, over-exploitation, environmental pollution, climate change and land-use changes. Efforts to develop integrative conservation approaches for the conservation of plant species are essential. Plant conservation strategies are important to support the development of livelihoods based on the sustainable uses of plants and promote the understanding and sharing of the benefits and functions of plants. In case study, we review the history of the development of Kirstenbosch National Botanical Garden and the development of other National Botanical Gardens in South Africa.

2. South African National Biodiversity Institute’s Contributions to Biodiversity and Conservation

The South African National Biodiversity Institute (SANBI) is a parastatal organization under the National Department of Environment, Forestry and Fisheries (DEFF). SANBI is responsible for the management, maintenance and development of South Africa’s network of National Botanical Gardens (NBGs). This is

part of other biodiversity related responsibilities linked with the country's National Environmental Management: Biodiversity Act (NEMBA) No. 10 of 2004.

Currently, SANBI manages 10 NBGs which are located in seven of the country's nine provinces, as well as a new garden: the Thohoyandou Botanical Garden in the Limpopo Province. This garden will become the 11th NBG. The aim of the NBGs is to grow, exhibit and protect the indigenous flora of South Africa. NBGs conserve more than 7400 hectares of natural vegetation and accompanying biodiversity within their boundaries. These NBGs promote and raise environmental awareness locally and internationally. The Botanical Society of South Africa (a non-governmental organization), established in 1913, supported the NBGs for more than 100 years (Willis, 2018).

These NBGs serve as sanctuaries for threatened species and can play a significant role in climate change adaptation. South African NBGs are centers of excellence for indigenous plants and are the providers of information and professional skills in horticulture and tourism. NBGs support national, regional and international networks for conservation, sustainable use and appreciation of the indigenous plants of South Africa, including the Kew Botanical Garden's Millennium Seed Bank Partnership (Willis, 2018).

Several of SANBI's NBGs—Free State, Harold Porter, Karoo Desert, Kirstenbosch, Lowveld, KwaZulu-Natal, Kwelera, Pretoria and Walter Sisulu National Botanical Gardens are classified as conservation gardens, because they have a combination of cultivated collections and areas of natural vegetation within each garden.

The Hantam NBG covers an area of over 6200 ha in the 'bulb capital of the world' (so-called because of its rich variety of naturally occurring bulb species). There are no fewer than 2200 species occurring in the region of which are endemic and threatened (Willis, 2018). This NBG is situated in the small town of Nieuwoudtville in the Northern Cape. This garden is classified as a 'natural or wild garden', conserving representative units of the region's local indigenous flora and fauna (Figure 3). SANBI's vision for this garden is to become a center for long term ecological monitoring and research. SANBI has potential partners, research institutions and tertiary academic institutions to make this vision a reality. Entomologists have discovered new insect species in this garden over the past few decades (Willis, 2018).

3. Case Study: Kirstenbosch Botanical Garden and History of Plant Conservation in South Africa

The Kirstenbosch NBG is a name that echoes around the world as the place of exclusively rich flora in a background of unsurpassed beauty. The development of Kirstenbosch NBG started soon after the unification of South Africa, on land that was set aside by Cecil John Rhodes. The garden celebrated its centenary in 2013. The Garden is located in Cape Town and is the first garden was situated close to the stream that flows off the north-facing slopes of Table Mountain (Huntley,

2012). The climate at Kirstenbosch is typical of the Mediterranean regions of California, Chile, southern Australia and the Mediterranean basin. It is warm with dry summers and cool, wet winters. The east-facing ridge rising high above Kirstenbosch accentuates the temperature and rainfall gradients of the Garden's climate and gives it a distinctive set of microclimates (Huntley, 2012). The Garden receives over 1300 mm of rainfall per annum and the mist and fog covering the lower reaches of the Garden on many autumn mornings is another characteristic. The average daily temperature is 25°C in summer, but it can reach up to 35°C, with February being the hottest month. July is the coolest month when the average daily temperature is 17°C and the coldest night drops down to 7°C. Autumn and spring average 18°C - 22°C.

KNBG covers an area of 199.2 ha and supports a diverse fynbos flora and natural forest. The cultivated garden (36 hectares) displays collections of South African plants, particularly those from the winter rainfall region of the country. The Garden's living collections include over 6000 species. Kirstenbosch is situated in the Cape's Floral Kingdom (CFK) so the emphasis at Kirstenbosch has always been on the fynbos, which is symbolized by three families such as *Proteaceae*, *Ericaceae* and *Restionaceae* (Figure 1). KNBG also has a rich diversity of bulb species (Huntley, 2012) and more than 7000 of Southern Africa's 22,000 plant species are grown here. The Garden has won several international awards with its exhibitions—33 gold medals, several gilt medals and one silver medal at the Royal Horticultural Society's Chelsea Flower Show in the United Kingdom. Visitor numbers to the garden have doubled from 400,000 in 1990 and is an important center for species conservation.

Theme gardens were developed in KNBG to enable visitors to follow, understand and remember the reasons for such groupings. These gardens include: the "Water-wise garden" visitors can see what is achievable in terms of structure, colour, resilience, economy and sustainability using species adapted to seasonal or long-term drought, "Fragrance garden"—this garden shows the diversity of scented plants that give fynbos its distinctive accents and notes, "Garden of extinction"—explains of the threats facing our flora, and successes that have been achieved by Kirstenbosch's Threatened Species Programme in propagating and reintroducing species which is extinct in the wild to their former habitats, and the 'Useful Plants garden—it attracts the most interest among school learners—the rich heritage of traditional plant use is presented here (Figure 1, Figure 2, Figure 3). One of the most important sources of traditional medicine, *Eucomis autumnalis*, is found here in this garden (Huntley, 2012). Having established the themed gardens, it was essential for KNBG to understand the workings of nature through conservation science.

The Kirstenbosch Research Centre (KRC) was established in the early 1990's with the aim to explore, predict and explain the impacts of potential climate on the vegetation and the flora of southern Africa. The climate-change work is one of SANBI's flagship programmes and enjoys international recognition. One of the



Figure 1. Some of the representative plant species found in Kirstenbosch NBG: (a) *Strelitzia reginae*; (b) *Agapanthus sp.*; (c) *Ursinia calenduliflora*; (d) *Protea cynaroides*; (e) *Encephalartos sp.*; (f) *Eucomis autumnalis*. Photos: Alice Notten, Kirstenbosch (PlantZAfrica).



Figure 2. Citizen science and outreach programmes: (a) & (b) The Conservatory, also known as the glasshouse; (c) the fragrance garden; (d) The tree canopy walkway, also known as the Boomslang (meaning tree snake); (e) the useful plants garden; (f) the garden of extinction; (g) Kirstenbosch NBG—Outreach Greening Programme; (h) Kirstenbosch NBG—Biodiversity Education Programme. Photos: Alice Notten, Kirstenbosch (PlantZAfrica).

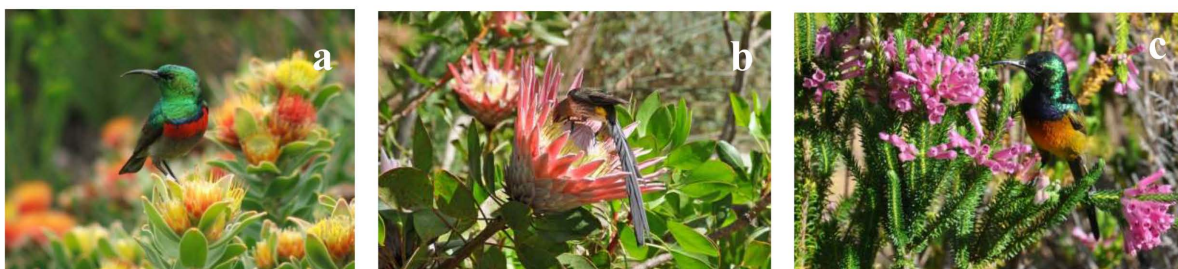


Figure 3. Bird species found at Kirstenbosch NBG: (a) Lesser Double-collared Sunbird (*Cinnyris chalybeus*) perched on a pincushion (*Leucospermum oleifolium*); (b) Sugarbird (*Promerops cafer*) feeding on the nectar in a King Protea (*Protea cynaroides*) flowerhead; (c) Orange-breasted Sunbird (*Anthobaphes violacea*) feeding on Whorled Heath (*Erica verticillata*). Photos: Alice Notten, Kirstenbosch (SANBI Kirstenbosch).

most quoted papers emerged from the research on *Aloe dichotoma* and equally important was a research project that investigated the responses of savanna trees to increased concentrations of atmospheric carbon dioxide (CO₂). The Protea Atlas Project, a Kirstenbosch initiative, was established in 1990. A small in-house team with many volunteer fieldworkers georeferenced a database of information on the distribution and abundance of any single family of plants, anywhere. This database is unique because it is linked to detailed environmental information on climate, soils, altitude, slope and aspect. This information provides the modeler with data for developing and testing ideas on the responses of species to changes in environmental factors (Huntley, 2012). Recently networks have been established by making use of the power of mobile phones, digital cameras and the internet to rapidly document information on butterflies, reptiles, frogs and spiders. Several of these networks have been incorporated and funded through the wider science network of SANBI (Huntley, 2012).

KNBG is playing a huge part in conserving the threatened group of living the fossils, the cycad. South Africa is one of the hot spots of cycad diversity, with 68% of its 38 species threatened with extinction and three of these species listed as Extinct in the Wild. The present status of cycads exists because of illegal trade. SANBI established within its network of gardens, a diverse gene bank of specimens that can be used in “captive breeding” programmes, possibly leading to the re-establishment in their original habitats.

The innovation of the Kirstenbosch “seed primer” enhanced seed germination of many fynbos species. After years of experimentation with combinations of heat intensity and frequency, different ash loads, in both the field and laboratory into the stimulation of seeds to germinate a smoke primer was used developed by researchers at KNBG and a 90% success rate was obtained for several fynbos species that had previously been im-possible to germinate (Huntley, 2012). Another feature of the research programme at the KNBG was the establishment of the molecular laboratory at the KRC in 2000. The programme has expanded from a focus on the evolution of proteas and other fynbos plants to the inclusion of animal groups with special importance in South Africa, such as reptiles and frogs (Huntley, 2012).

4. Role of Botanical Gardens in Preservation of Plants and Traditional Herbal Uses

Medicinal plants are internationally valuable sources of new herbal products or drugs, and these plants are disappearing at an alarming rate (Chen et al., 2016). More 1300 medicinal plants are used in Europe of which 90% are harvested from wild populations and in the USA about 118 of the 150 prescription drugs are based on natural sources (Bentley, 2010). In developing countries, 80% of the people are totally dependent on herbal medicine for their primary healthcare. There is an increased demand worldwide for traditional herbal medicine (Chen et al., 2016). The International Union for Conservation of Nature (IUCN) and the World

Wildlife Fund (WWF) reported that there are between 50,000 and 80,000 flowering plant species used for medicinal purposes worldwide of which 15,000 species are threatened with extinction from overharvesting and habitat destruction (Balunas & Kinghorn, 2005). For medicinal plants with increasingly limited supplies, sustainable use of wild resources can be an efficient conservation alternative. The situation in South Africa is particularly critical because of the high demands of large populations (Chen et al., 2016).

A few plant families do not have higher numbers of medicinal plants, but also have higher quantities of threatened species than others (Huang, 2011). Various sets of recommendations relating to the conservation of medicinal plants have been developed, such as providing both in situ and ex situ conservation (Huang, 2011). Natural reserves and wild nurseries are examples to preserve the medical value of plants in their natural habitats, while botanic gardens and seed banks are important examples for ex situ conservation and future re-planting (Sheikh, Ahmad, & Khan, 2022; Coley et al., 2003). Geographical distribution and biological characteristics of medicinal plants must be known to guide conservation activities, e.g. to determine whether species conservation should take place in the wild or in a nursery (Chen et al., 2016).

Most of these plants are endemic species, and their medicinal properties are primarily because of the presence of secondary metabolites that respond to stimuli in natural environments, and that may not be expressed under cultured conditions (Coley et al., 2003; Figueiredo & Grelle, 2009). In situ conservation of whole communities permits us to protect endemic plants and maintain natural communities, along with their complicated network of relationships (Gepts, 2006). This type of conservation increases diversity that can be conserved (Forest et al., 2007) and strengthens the link between resource conservation and sustainable use (Long et al., 2003). Effective in situ conservation depends on rules, regulations and potential compliance of medicinal plants within growth habitats (Soulé et al., 2005; Volis & Blecher, 2010).

Ex situ conservation cannot be separated from in situ conservation, but it serves as an effective complement to it, especially for overexploited and endangered medicinal plants with slow growth, low abundance, and high susceptibility to re-planting disease (Hamilton, 2004; Havens et al., 2006; Yu et al., 2010). The role of ex situ conservation is to cultivate and naturalize threatened species to ensure their continued survival and sometimes to produce big quantities of planting material used in the manufacturing of medicine, and it is often an immediate action taken to sustain medicinal plant resources (Swarts & Dixon, 2009). Several species of previously wild medicinal plants can not only preserve high potency when grown in gardens far away from their natural habitats but can have their reproductive materials selected and stored in seed banks for future replanting (Hamilton, 2004).

The botanic gardens play a significant role in ex situ conservation (Havens et al., 2006) and they can maintain the ecosystems to enhance the survival of rare

and threatened plant species. Living collections usually consist of only a few individuals of each species and are therefore of limited use in terms of genetic conservation. Botanic gardens have multiple unique characteristics and involve a wide variety of plant species grown together under the same conditions (Primack & Miller-Rushing, 2009). Botanic gardens can play an additional role in medicinal plant conservation through the development of propagation and cultivation protocols, as well as undertaking programs of domestication and variety breeding (Maunder, Higgens, & Culham, 2001). Seed banks present a better way of storing the genetic diversity of many medicinal plants *ex situ* than through botanic gardens. These seed banks are recommended to help preserve the bio-logical and genetic diversity of wild plant species (Li & Pritchard, 2009). The Millenium Seed Bank Project at the Royal Botanic Gardens in Britain of which the KNBG is part of is the most note-worthy seed bank. Seed banks permit rapid access to plant samples for the evaluation of their properties, providing valuable information for conserving the remaining natural populations (Schoen & Brown, 2001). One of the most challenging tasks of seed banking is the reintroduction of plant species back into the wild and how to actively assist in the restoration of wild populations.

5. Role of Botanical Gardens in Plant Research and Diversity

Botanical gardens are useful locations for many branches of scientific research. These gardens not only function as taxonomic and systematic research centers (Dosmann, 2006; Stevens, 2007) they also play a significant role as valuable sources of plant ecology data collection such as phenological indication of climate change, plant physiology and plant growth methods, and plant-animal interactions (Coates & Dixon, 2007; Gratani, Crescente, & Varone, 2008; Dawson, Burslem, & Hulme, 2009; Wang, Phillips, & Tomlinson, 2018). These gardens can provide large sets of species to study functional trade-offs between species traits and plant performance for plant functional performance (Herben, Nováková, & Klimešová, 2012). The achievement of botanic gardens as scientific institutions has also been reinforced by their ability to use their scientific resources to respond to current issues.

In the past, science in botanic gardens focused on issues such as plant-based medicines i) and economically important plants such as fruit trees ii). Some research in these areas is continued in many gardens. Recently, botanic gardens have also become suitable locations for investigations into pollination ecology, seed dispersal, and other interactions between plants and animals. A study of seed dispersal in an endangered species, *Taxus chinensis*, in an *ex situ* conservation population introduced into the Nanjing Botanical Garden in the 1950s, researchers were able to propose that any process for the conservation of these Chinese coniferous trees/shrubs (yews) should include not only conservation of the trees, but also conservation of these tree's avian dispersers and habitats for seed germination and seedling growth (Lu, Zhu, & Deng, 2008; Li, An, & Liu, 2014).

Research done at botanic gardens has guided conservationists not to neglect the

possible risks of hybridization in ex situ collection of threatened plant species. Especially, spontaneous hybridization in ex situ facilities has been shown to undermine the genetic integrity of ex situ collections and may contaminate open-pollinated seeds or seedlings (Zhang, Ye, & Yao, 2010). Effective conservation and management of the ex situ population of endangered species in botanical gardens, pollination ecology, including breeding system, effective pollinators and other factors should be monitored carefully (Chen & Sun, 2018; Chen et al., 2016; Zhang, Ye, & Yao, 2010).

6. Role of Botanical Gardens in Systematics

Herbaria and living collections in botanic gardens form a data bank of global plant life and play a key role in advancing the knowledge of biological diversity. A lot of herbaria located in botanic gardens serve to support scientific studies in the identification and classification of species (Delmas, Larpin, & Haevermans, 2011). Living collections serve a complementary role for fieldwork and herbarium studies. The study of living collections is valuable for the development of monographs and flora for plants that cannot easily be preserved as herbarium specimens. Monographs and floras are also valuable for systematic, molecular and phylogenetic studies and enable the study of plants whose original locality has been destroyed or is inaccessible (Delmas, Larpin, & Haevermans, 2011). Additionally, they also serve as a valuable source for research in biogeography, plant physiology, pharmaceutical biology, conservation and restoration research (Borsch & Lohne, 2014) and can be performed by gardens of varying size (Delmas, Larpin, & Haevermans, 2011). Kirstenbosch over the years have been involved and invested in molecular analysis and phylogenetic relationships of insect, plant (McLeish et al., 2011) and amphibian species through time, and examining climate change impacts on species through phylogenetic reconstructions.

7. Contributions at National and International Level to Plant Conservation and Climate Change

Plant diversity is not evenly spread around the globe and one of the main activities in conservation biology is the identification of priority areas for conservation. Spatial information obtained from herbarium specimens, together with other species databases, has been used to understand patterns of endemism and diversity, identify so called “hotspots” of biodiversity (Bradford & Jaffre, 2004; Forest et al., 2007) and to prioritize areas for conservation. Species distribution data have been used to identify species that occur at a single site so that it can be protected (Ricketts et al., 2005). Presently conifers are the only plants that have been included in such global analyses due to the absence of comprehensive conservation assessments for other plant species. Complex analyses have used algorithms to prioritize sites based on multi-species distribution data and the application of conservation-planning principles to identify sites that fully represent the biodiversity components that need to be conserved and will provide the conditions necessary for

long-term persistence. Earlier developments in conservation-planning methodologies were linked to specimen data and contributions from botanic gardens. (Rebello & Siegfried, 1993).

Living collections, especially of species that are threatened with extinction, have a long tradition in botanic gardens and have significant contribution to the body of knowledge on threatened species and their conservation (Guerrant et al., 2004) for example was the study of ex situ cycad collections at Fairfield Tropical Botanical Garden in Florida, USA. This study has led to the first experimental evidence of insect pollination in these fossil plants (Norstog, Stevenson, & Niklas, 1986). These plants have a high risk of extinction, and the knowledge of their pollination systems has resulted in conservation plans that consider their dependence on specialist pollinators (IUCN, 2003). Ex situ conservation is regarded as a means of supporting conservation in the wild and has been an active area of research in botanic gardens. A synthesis in 2004 of the science and practice of ex situ conservation (Guerrant et al., 2004) highlighted the scientific contributions from botanic gardens to the main stages involved in the process, ensuring that: i) what goes into ex situ collections is representative of the genetic diversity of the taxon and is sufficient to re-establish viable populations (Cochrane, Crawford, & Monks, 2007); ii) reintroduced populations are ecologically and genetically viable (Maschinski, Baggs, & Sacchi, 2004). This process needs a complete understanding of population genetics and many laboratories in the botanic gardens have made valuable contributions to understanding the genetic structure of threatened species (Cariaga et al., 2005) and the genetics of ex situ collections and reintroduced populations (Goodall-Copestake et al., 2005).

A long history of the contributions that botanical gardens made towards plant science and have played a leading role in the development of areas such as plant taxonomy, systematics, horticulture and are good locations for scientific research (Chen & Sun, 2018) exist. The botanical gardens contain a combinations of features that are unusual compared to other sites of long-term ecological and physiological research (Primack & Miller-Rushing, 2009). Many species are grown together in the gardens that could not be found growing together under natural conditions and have been collected from all over the world. As a result, botanical garden collections can include taxonomically and ecologically diverse flora with extensive representation from particular genera or families. The diversity and depth of taxonomic representation facilitate comparative evolutionary, ecological and phylogenetic studies (Primack & Miller-Rushing, 2009; Debussche, Garnier, & Thompson, 2004; Karlson et al., 2004; Miller-Rushing et al., 2007). Botanical gardens have kept precise records on plants (Dosmann, 2006) and the Royal Botanic Gardens in Edinburgh and Kew have records of plant phenology that date back to the 19th century (Harper & Morris, 2007).

Botanical gardens face challenges and opportunities in responding to global change, and specifically climate change. These gardens have a unique set of resources that enable them to undertake climate change research projects not easily

carried out elsewhere (Primack & Miller-Rushing, 2009). Several recent changes in the behaviour of plants and animals reflected the effects of climate change. Researchers have observed birds migrating earlier in the spring (Primack & Miller-Rushing, 2009; Lehikoinen, Sparks, & Zalakevicius, 2004; Gordo, 2007), decreases in population sizes of some animal and plant populations (Willis, 2018; Primack & Miller-Rushing, 2009; Moller, Rubolini, & Lehikoinen, 2008). There is evidence that some plant populations, insects and other animals are relocating to higher altitudes and locations closer to the poles (Parmesan & Yohe, 2003). Significant evidence of biological responses to climate change is evident from work demonstrating changes in the flowering and leaf-out times of temperate and arctic plants which are sensitive to warm weather in the spring (Primack & Miller-Rushing, 2009). Flowering and leaf-out data are convincing because they are abundant and because phenology is closely coupled with climate (Primack & Miller-Rushing, 2009; Parmesan, 2007). Botanical gardens have been suppliers of these data through their staff members who recorded the flowering and leafing dates of plants in their collections (Primack & Miller-Rushing, 2009; Miller-Rushing et al., 2007; Menzel & Fabian, 1999).

Spatial and temporal information deposited in herbaria has been an important starting point for studies on the projected impacts of climate change. Bioclimatic models have been applied to project possible changes in the geographical range of species in response to these changes (Midgley et al., 2002; Bomhard et al., 2005; Broennimann et al., 2006; Midgley & Thuiller, 2007). These models depend on current and historical distribution data to identify the habitat and climatic variables that can explain the geographical range. Many of the data originates from herbarium specimens. Scientists in botanical gardens have been leading the modelling of species responses to climate change, with work on the Cape Flora in South Africa (Midgley et al., 2002; Midgley & Thuiller, 2007) and British lichens (Ellis et al., 2007) as examples of this approach. Modelling approaches have been inhibited by limited data derived from herbarium specimens which include incomplete sampling from across the entire geographic range of a species and the fact that herbarium records provide only presence data, which do not necessarily provide solid evidence of the absence of a species from a particular site.

Data that strengthens studies on the impacts of climate change and habitat loss is specimen data. This data can be complemented by other data (e.g. plant atlas data) to provide information about areas where a species is absent and this data has been collected by botanic gardens and other institutions (Bomhard et al., 2005; Binder & Ellis, 2008). Other innovations to obtain more information on plant responses to climate change from herbarium collections include time-series analyses of changes in carbon content (Primack & Miller-Rushing, 2009) and phenological changes (Miller-Rushing et al., 2004; Miller-Rushing et al., 2006). Herbarium records from 1950 to 2007 in an Australian study was used to detect species in which the flowering response was sensitive to temperature (Gallagher, Hughes, & Leishman, 2009). This study identified a subset of species that might be suitable for

long-term monitoring of climate change impacts.

Botanical gardens should be in an ideal position to monitor plants in their collections and undertake experiments to answer questions relating to conservation and climate change given they have the facilities and expertise for growing plants. Monitoring plant phenology (Gallagher, Hughes, & Leishman, 2009) is regarded as one of the most sensitive indicators of climate change impacts on vegetation in mid-latitudes (Menzel et al., 2006). Warming experiments have been undertaken in gardens and in the field, providing evidence of possible impacts of climate change on plant growth and survival. A recent study of succulent species from southern Africa suggests that a slight increase in temperature will lead to rise in mortality (Musil et al., 2009). A recent survey about research on climate change impacts and biological invasions in botanic gardens indicated that the gardens seem to be missing an opportunity to increase the impact of their contribution to global-change research.

8. Conclusion and Future Prospects

Botanical gardens are contributing significantly to conservation biology and global change science across a range of disciplines. Collections in herbaria, one of the major resources of botanic gardens, are valuable information centers to inform conservation planning and to add to the understanding of global change impacts. These collections can be strengthened by improving data quality and by including information on threat status of plants.

Changed human actions, such as in situ/ex situ conservation experiments and horticultural processes in botanical gardens, are bringing previously isolated populations and species into contact. Important advances in ex situ conservation have been made, especially seed banking, as well as in reintroduction and restoration methods. Further research on restoration methods, specifically in areas with high biodiversity, needs to be done. The living collections and growth facilities that are being used for research in botanical gardens are under-utilized and it was concluded that only a few gardens are actively involved in conservation biology and global change research. Botanical gardens should play leading roles in the development of plant information data base to monitor environmental parameters in gardens. There should be an acceleration in global access to plant diversity information which managers from different gardens need.

The KNBG and other botanical gardens have many successes, including its focus on indigenous plants, its role in conservation, and its popularity with tourists. Most of the botanical gardens in South Africa are facing financial constraints and are forced to diversify to survive. In the future, botanical gardens nationally and internationally need to extract more value from living collections to address conservation and climate change questions and problems.

Investigations of the responses of species to climate change and changes in invasion capacity can be increased if these investigations can occur through a network of botanic gardens with different environmental conditions. These types of

collaborative projects will draw funding and will provide opportunities for capacity building for research by bringing together gardens in developed and developing countries. Science in gardens also needs to confront the challenge of an increasing focus on ecosystem services and this service can benefit the strengths of botanic gardens.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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