


BGCI Technical Review

The susceptibility of botanic gardens, and their responses, to natural and man-made disasters





BOTANIC GARDENS CONSERVATION INTERNATIONAL

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PREPAREDNESS FOR RESPONSE IS A CRITICAL ELEMENT FOR RESILIENCE

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Contents

1. Introduction

Fire at sunset, view from Blue Mountains Botanic Garden Mount Tomah, New South Wales. (Greg Bourke)

The global COVID-19 pandemic has focused all of our minds on the susceptibility of our physical and mental health, economic systems and cultural norms to disruption from global disasters. However, albeit the most disruptive so far, the COVID-19 pandemic is only the latest in a series of global, regional and local disasters over the past decade, including increasing incidences of drought, fire, floods, hurricanes and more localized pest and disease outbreaks. Many of these disasters are linked to man-made climate change and, recalling the Stern Review of the Economics of Climate Change published in 2007, it is frightening how quickly that report's predictions have come to pass. In this Technical Review, given the difficulty in attributing the specific causes of disasters, we don't try to differentiate between disasters that are 'man-made' and 'natural'. However, because of the dominant influence of humans on the ecosystems of this planet, our assumption is that people play a part in most of the disasters that befall us. This means that, in theory at least, mitigating measures are possible. However, tackling the causes of climate change, for example, is a long-term undertaking and in the short to medium term our only viable options are to adapt. The primary purpose of this Review is to explore how we can best do this, based on our exposure to, and management of, disasters up until now.

Botanic gardens are particularly vulnerable to climate-related disasters, as these affect both people and plants. On the other hand, we are less vulnerable to pandemics like COVID-19 than indoor venues because we can safely accommodate larger volumes of visitors. So, while we can undoubtedly learn from other sectors, we also encounter challenges that are unique to our community. For this reason, this Review focuses on what we can learn from each other in the botanic garden/arboretum sector. The Review looks first at the nature, frequency and impacts of man-made natural disasters in botanic gardens over recent years, then at how such disasters are managed, including sources of assistance, management actions and adaptation to more resilient infrastructures and practices in the longer term. These management responses are primarily illustrated by case studies from around the world. In total, this Review incorporates data from 91 institutions in 44 countries, including 24 case studies. Finally, the Review lists sources of information and ways in which gardens can seek assistance should they be unfortunate enough to be affected by any of the disasters covered in this Review.

2. Methods

This Review has been compiled using the findings of an online survey of botanic gardens, arboreta and other institutions conducted in early 2021, which we subsequently refer to using the general term 'botanic gardens'. The survey questions were designed to enable analysis of information provided on a wide range of aspects relating to the susceptibility of botanical institutions to disasters and their responses to these. Specifically, this included the types of disasters and their impact, frequency and duration, nature of support required and received, institutional policies and plans to manage disasters, capacity building needs, and forward planning. Pest and disease outbreaks, including alien invasive species, were excluded from this Review as they are extensively covered in numerous other analyses. Nevertheless, respondents had the option to highlight these when applicable. When considering the data summarized in this Review, the following should be noted:

- For some institutions, double or multiple entries were found which were subsequently combined into a single, institutional record;
- Not all institutions completed all questions, resulting in varying n-values per question;
- For some questions, multiple answers could be selected;
- A few institutions did not answer the survey but provided case studies.

In total, this Review incorporates data from 91 institutions in 44 countries, including 24 case studies from 21 countries (Annex 1).

Cruz Coberta stream in spate in the Jardim Botânico Araribá, Brazil, following torrential rains. (Guaraci M. Diniz Jr.)

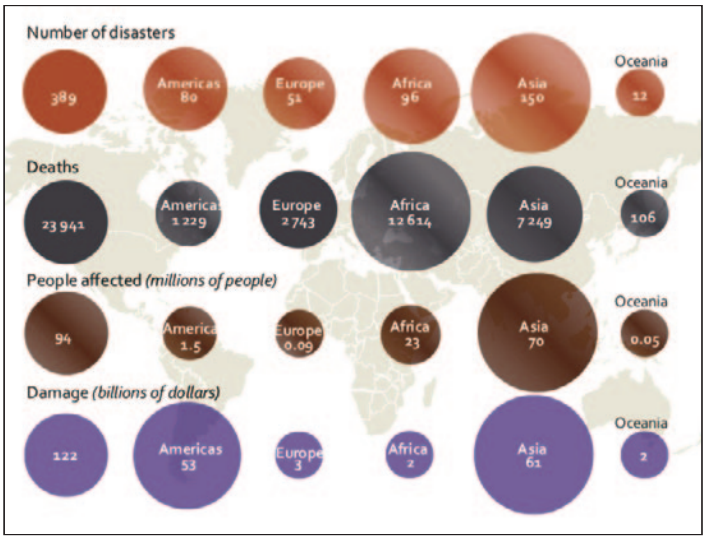
3. Botanic gardens and natural and man-made disasters

Burnt palmiet (Prionium serratum, Juncaceae), in the Dawidskraal River, Harold Porter National Botanical Garden, South Africa, 15 January 2019. Palmiet, endemic to South Africa, plays an important ecological role in protecting riverbeds from erosion. (Christopher Willis)

3.1 Nature and magnitude of disasters affecting botanic gardens

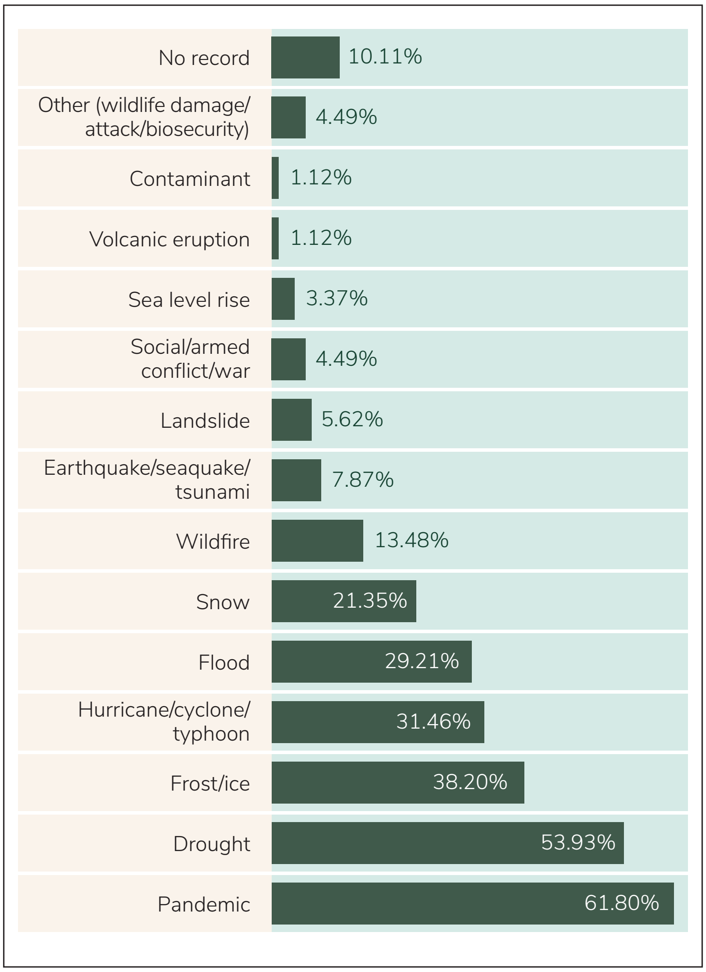
Natural and man-made disasters strike communities around the world each year, and there is a growing realisation and evidence that their frequency and impact are becoming more prevalent (Munich RE 2021; World Economic Forum 2020; IPCC 2019 and 2021) worldwide. In addition to the COVID-19 pandemic, other recent events that have had widespread media coverage are the wild fires in Australia in 2019, heavy snow in parts of southern Europe in 2020, soaring temperatures in North America and Canada in 2021 and torrential rains and inundations in central and eastern Europe in 2021. Collectively, these disasters have caused enormous devastation and loss of life. According to the International Disaster Database of the Centre for Research on the Epidemiology of Disasters (EM-DAT CRED), in 2019 alone, a total of 389 disasters caused by natural phenomena around the world left nearly 24,000 people dead, another 94 million affected with damages estimated at some USD 122 billion. At the global level epidemics were the cause of the greatest number of deaths (51% of the total), followed by floods (21% of the total). Extreme events such as storms, floods and droughts affected over 90 million people throughout the world (97% of the total affected population). The most damage (USD 58 billion) was caused by storms, followed by floods (USD 36 billion) and forest fires (USD 26 billion), with these three causes accounting for 98% of all damage caused by disasters during that period (CRED 2020 in Bello et *al*. 2021) (Figure 1).

FIGURE 1: DISASTERS: OCCURRENCE, DEATHS, POPULATION AFFECTED AND DAMAGE IN 2019. FROM BELLO *ET AL*. 2021 BASED ON DATA BY THE CENTRE FOR RESEARCH ON THE EPIDEMIOLOGY OF DISASTERS (CRED), EM-DAT INTERNATIONAL DISASTER DATABASE.



As with other institutions, botanic gardens have not been spared the calamitous effects of natural and man-made disasters. Collections, infrastructures, botanic garden personnel and visitors have been exposed to manifold hazards, including fires, droughts, extreme cold and frosts, storms, floods, landslides, earth-/seaquakes, sea level rise, volcanic eruptions, pandemics, contaminants, social unrest, armed conflict and war, etc. (Figure 2). Some institutions are struck by disaster year after year. The Botanical Garden of Vilnius University, Lithuania, for example, experienced severe late frost in 2017, drought in 2018, floods in 2019, the COVID-19 pandemic in 2020-21, and heavy snow in 2021. What is more, multiple events can hit institutions coincidentally or in quick succession, challenging their response and management abilities to their limits or incapacitating them completely. For instance, Joseph Reynold O'Neal Botanic Gardens in the British Virgin Islands was hit twice in September 2017 by powerful hurricanes of category 5 within an interval of just 10 days (see Case study Joseph Reynold O'Neal Botanic Gardens). Andromeda Botanic Gardens in Barbados was covered under a layer of ash generated by the eruption of the La Soufrière volcano in St Vincent in April 2021, whilst the Garden was already grappling with the effects of the COVID-19 pandemic (see Case study Andromeda Botanic Gardens).

FIGURE 2: EXPOSURE OF BOTANIC GARDENS TO DIFFERENT TYPES OF DISASTER (N=89; 43 COUNTRIES)



COVID-19 PANDEMIC

With the survey being conducted whilst the coronavirus (COVID-19) continued to turn the world upside down, it is not surprising that the respondents rated 'pandemic' as the most widespread and impactful disaster that has struck the global botanic garden community to date. This is emotively illustrated by statements such as "Two years ago, a pandemic would not likely have found its way onto our risk assessment list" and "Droughts can last up to eight months and can cause permanent plant specimen loss.

CASE STUDY: **Shanghai Chenshan Botanical Garden's Internet Flower Show, China**

Hu yonghong and Zhang zhe

Late in January 2020, Shanghai Chenshan Botanical Garden in China closed to visitors due to the COVID-19 pandemic. With the arrival of spring, the spectacular sakura blossoms started to appear - a sea of cherry tree flowers covering an area of 6,000 m^2. The opportunity of bringing hope and spring to the homes of the Chinese people during lockdown could not be missed by the Garden. The 'Internet Flower Show' was launched, and the first episode "Sakura is blossoming in Shanghai" was broadcast live, receiving 1.5 million citizens' views nationwide. Since then, this online show has presented 50 episodes featuring many other flowering events at the Garden including orchids, begonias and plum trees. The 'Internet Flower Show' has recently evolved into a more specialist platform where plant and flower enthusiasts can interact virtually with the horticultural staff at Chenshan Botanical Garden and learn more about the Garden's plant collections. The Garden keeps innovating and launching new media projects like the celebration of the 10th anniversary of Shanghai Chenshan Botanical Garden, where the pianist Song Siheng performed live for a virtual audience from one of the Garden's conservatories. Technology and media have allowed the Garden to keep in touch with the wider public and send a message of unity in difficult times.

Sakura blossom at Shanghai Chenshan Botanical Garden. (Shanghai Chenshan Botanical Garden)

Damage from storms is temporary resulting in days lost due to being closed (usually just a day or two), but very costly in terms of clean-up. The pandemic, which is ongoing, is a complete and utter disaster". It is likely that the impact of this pandemic may linger on for some considerable time with long-lasting effects on the mental health and well-being of botanic garden staff. On the other hand, the COVID-19 pandemic has also undoubtedly demonstrated the resilience of botanic gardens, and impressively illustrated their capacity to adapt and innovate under great pressure. As with other institutions, most botanic gardens went into lock-down, many of them suspending visits from the 750 million visitors who visit botanic gardens worldwide in a normal year. However, many gardens swiftly adjusted to the new situation, engaging the public through a variety of outreach media to remain connected and provide virtual platforms to meet (BGCI 2020).

CASE STUDY: **Managing the COVID-19 pandemic at Kepong Botanic Garden, Malaysia**
Suhaida Binti Mustafa

Kepong Botanic Garden was established in 1996 and is part of the Forest Research Institute of Malaysia (FRIM). The Garden is located in the foothills of Hari Hill, 20 km from Kuala Lumpur, and extends over 80 hectares comprising 50% forested hillslopes, 35% undulating plains, and 15% water bodies.

The COVID-19 pandemic has impacted FRIM and the Garden significantly. During the lockdown imposed by the government, only 20-30% of the staff were allowed into the office, and priority was given to essential services. Under this arrangement, Garden staff continued the daily routine of maintaining and monitoring the living collections. However, acquisition of fresh germplasm through field trips was suspended. Much of the research and development plans for 2020 and 2021 were also put on hold.

The pandemic has had both positive and negative effects. The absence of visitors and the ensuing peace has attracted a variety of wildlife to venture into the Garden; boars, macaques and beavers are frequent visitors. The sounds of birds and insects have become nature's orchestra culminating in a daily crescendo at dawn and dusk. Since its inception, Kepong Botanic Garden has played a crucial role in maintaining physical and mental well-being of the local residents. The closure of the campus was of great concern to the residents, in addition to the loss of income to the garden generated annually through recreational and tourism activities before the pandemic.

Until now, FRIM's disaster management strategy in response to the pandemic has been straightforward, as the government intermittently enforced total lockdowns across all states in the peninsular. During the periods of permitted movement, the Garden remained closed because the benefits of closure far outweighed the negative impacts. It is worth noting, however, that the Garden does not receive substantive financial support from external stakeholders, which significantly reduces the pressure on visitor management. In conclusion, the Garden closure has benefited wildlife enormously and the living collections continue to thrive. On the other hand, research and development activities were significantly affected.

Among the important lessons that we learnt from this pandemic is the need for a responsive disaster management plan which is practical and effective. It is essential to identify and focus on the implementation of its most important objective, in this case to reduce viral transmission. The effectiveness of FRIM's disaster management strategy is based on a quick response to contain the situation, placing health as the highest priority. In view of the gradual relaxation of lockdown, FRIM is currently reviewing the Garden's strategy to allow for a cautious return of its functions and roles.

Kepong Botanic Garden, Malaysia, under COVID-19 lock-down. (Suhaida Binti Mustafa)

Reminiscing the founding of the Botanical Garden of Tver State University as a means of public engagement during the COVID-19 pandemic. (Botanical Garden of Tver State University)

CASE STUDY: **Coping strategies during the COVID-19 pandemic at the Botanical Garden of Tver State University, Russian Federation**
Yurii Naumtsev

Founded in 1875, the Botanical Garden of Tver State University, is located in the temperate region of Central Russia. Owing to the coronavirus pandemic, the Garden closed to the public for five months in 2020. The closure meant a decrease in revenue from visitors. The led to a financial crisis, since the income from the sale of entrance tickets represents the main income resource for maintaining the landscape and the collections, as well as for paying the salaries of the employees. It is worth noting that the Garden was closed between March and July, a period when it is most visited. During that period, no more than two employees per day could work in the Garden at the same time. For a garden of 2.5 hectares and collections representing about 4,000 species, this has a critical impact.

As with many other institutions, the Garden has faced a pandemic and quarantine for the first time. Nevertheless, the Botanical Garden of Tver State University has a management strategy to mitigate and eliminate the effects of natural and man-made disasters. Key elements of this strategy include competent social marketing and work with the local community, and mutual support programmes with other botanic gardens. The Garden received modest financial support from the Special Fund of the Landscape Arboretum of the University of Minnesota (USA) and both institutions have signed a Memorandum of cooperation and support. However, the maintenance of the Garden and its plant collections was primarily made possible thanks to the support by the local community.

Volunteers helped us to maintain or restore the garden grounds and plant collections during and after the quarantine period. Support also included special open donation programmes for the purchase of garden tools, soil, fertilizers and other care and protection products for plants, planting material, etc. Special events, including flower exhibitions, master classes, concerts, etc., jointly organised with the local community helped to quickly attract additional funds to the Garden immediately after the end of the quarantine. All this was made possible thanks to the Garden's outreach strategy, which helped to maintain close contact and communication with the local community during the quarantine period. This included online engagement through social networks, regional media, etc. with special attention given to culturally emotive contents. We use the practice of creative project alliances to create content with the illusion of real presence and emotional involvement rather than mere virtual tours and photos of plants and displays. We worked to create virtual content about our botanic garden together with musicians, artists, actors, and filmmakers from the local community. Worth mentioning also is that the Garden provided free medicines and food derivatives of plants that we grow to the local community. This is only one but an important part of an institutional strategy for managing a botanic garden during or following a disaster event.

As a result, we managed to fully preserve and maintain the Garden's landscape and the plant collections. Nevertheless, efforts are under way to refine the Garden's disaster management strategy. We find it very important to share best-practice disaster management strategies for botanic gardens, and endeavour to make our experiences available to other gardens in Russia to enhance management capacity in the event of future disasters.

CASE STUDY: **Facing the pandemic at the Jardín Botánico La Paz, Bolivia**
Esther Valenzuela Celis

The Jardín Botánico La Paz is part of the Universidad Mayor de San Andrés in La Paz, Bolivia. Inaugurated in 1991, the Garden is situated at 3,400 m above sea level and extends over five hectares. The climate is varied, with average temperatures ranging from 10 to 20 ° C, and scarce and irregular rainfall. Located in an urban area, the Garden exhibits geomorphological features typical of the La Paz valley, which makes it one of the few urban spaces that still conserves important elements of the biodiversity of the region's dry valleys. It has never faced any major disasters until the pandemic hit in March 2020. Due to the public health emergency, the Garden suspended its activities, and only a few staff continued to have access to the Garden to maintain the living collections. Research and educational programmes at the Garden were discontinued. This had an impact on teachers and students at the university as the Garden is used as an outdoor classroom and laboratory. Guided school and public tours were cancelled since the beginning of the pandemic, and funding for maintenance work at the Garden has been delayed for over a year. As Bolivia continues to be affected by the pandemic, the Garden is facing staff and institutional restructuring. A new organisational strategy to better adapt to the new situation caused by the pandemic is in development.


A deserted venue – Jardín Botánico La Paz during the COVID-19 pandemic. (Esther Valenzuela Celis)

DROUGHT AND FIRE

Increasingly intense and regular droughts present a hazard of similar order of magnitude to the COVID pandemic, with over half of the respondents highlighting droughts as major harmful events. Increasingly, drought is having an effect on the global community as a whole, with over 70 countries worldwide affected (UNCCD n.d. and Box 1). This is illustrated by the large number of botanic gardens in Africa, Asia, Australia, the Americas and Europe whose collections and facilities have been exposed to the impacts of drought (Figure 2). As regular drought facilitates the generation and spread of wild fires, combined these events account for the most significant disasters that botanic gardens are grappling with, representing over 67% of disasters identified in this survey. This statement is illustrative: "Droughts and fires are becoming more frequent and intense each year. There was a severe fire in the wilderness area of the botanic garden in 2003, and for the last ten years, it has been raining less and less. Precipitation recorded by the garden's weather station shows that rain has decreased by 40-50% in recent years". Although dryland floras are highly adapted to drought, and fire and smoke are well-known to trigger germination and growth in certain groups of plants (e.g. Ramos *et al.* 2019; Soós *et al.* 2019; Van Staden et *al.* 2000), the harmful effects of increasing intensity of high temperatures, droughts and fires even on these highly adapted species, speaks for itself. "Some of the plants will recover, seed of some will be stimulated to germinate and grow once it rains to sustain them – but in some cases because of the intensity of the heat there may be little recovery. For those animals that survived the fires a lack of vegetation and flora is concerning as that provides food resources and a habitat" (RBGSYD n.d.).

However, as resilient organisations, botanic gardens are also making a virtue out of necessity and are steadily adapting to the risks posed by drought and fire. For example, the Red Butte Garden, Salt Lake City, is developing research programmes to study vegetation comeback following fire. By the same token, the Australian Institute of Botanical Science which unites all of the scientific facilities, programmes and living collections across all botanic gardens in Sydney, is closely monitoring and evaluating recovery of affected plant populations. Working closely with the government and other institutions, efforts include: assessing existing knowledge; conducting field research and surveys both within and outside of the burnt areas; establishing long-term monitoring projects; documenting biodiversity and how it is affected by fire; collecting seed, and; using seed stored in the seedbank to aid research, propagation and recovery in the wild. The herbarium collection and associated data play a critical role in this work by providing baseline data for most species whilst being the repository of new collections and data made through this research (RBGSYD n.d.).

BOX 1: UNITED NATIONS CONVENTION TO COMBAT DESERTIFICATION (UNCCD)

Established in 1994, the United Nations Convention to Combat Desertification (UNCCD) is the legally binding international agreement linking environment and development to sustainable land management. The Convention specifically addresses the arid, semi-arid and dry sub-humid regions, known as the drylands. The >195 parties to the UNCCD work together to improve the living conditions for people in drylands, to maintain and restore land and soil productivity, and to mitigate the effects of drought. The UNCCD's Intergovernmental Working Group on Drought is developing policy measures and actions to help the people most vulnerable to drought to take early action to avoid loss of life, and the heavy and growing losses of livelihoods and damage to property and ecosystems following droughts. Botanic gardens have a role in bringing to bear their technical knowledge and practical knowhow as regards preparing for, responding to, recovering from and adapting to drought and the effects of wildfires to enhance the implementation of the objectives of the UNCCD.

CASE STUDY:

Bushfire impacts at the Blue Mountains Botanic Garden Mount Tomah, NSW, Australia

John Siemon

The Blue Mountains Botanic Garden Mount Tomah (BMBG) is one of three botanic gardens that make up the Royal Botanic Gardens & Domain Trust, New South Wales, Australia. Sitting atop a rich basalt capped mountain at 1,000 m above sea level, the Garden is located within the Greater Blue Mountains World Heritage Wilderness Area. The Garden is Australia's highest elevation botanic garden and is located approximately two hours drive west of Sydney city. The stunning wilderness surrounding the site provides geographic isolation and the Garden's altitude, basalt soil and cool climate make it one of the few locations in Australia well suited for the collection and conservation of cool-climate, high altitude plant species. The living collection displays more than 5,000 taxa including collections of North American and Eurasian Woodland species. The Garden is host to the first *ex situ* planting of the famous relict Wollemi Pine (*Wollemia nobilis*) and played a key role in the identification and conservation of the species which was discovered in the wild and rugged Wollemi National Park to the north. The Garden is surrounded by Blue Mountains Basalt Forest, an Endangered Ecological Community, which is dominated by stands of *Eucalyptus fastigata* (over 30 m in mature stands) with a dense shrub or small tree layer, often including tree ferns (*Cyathea* spp.) and moist herbaceous ground cover.

The biggest threat to the Blue Mountains Botanic Garden living collection is fire. On 26 October 2019, the Gospers Mountain megafire started from a single ignition point, a lightning strike. Over the coming 79 days it destroyed more than 350,000 hectares, an area seven times the size of Singapore. By the 19 December 2019, the Black Summer fires reached BMBG where it burnt over 90% of the Garden's 250 ha of natural vegetation and more than 500 of the Garden's prized specimens from the living collection. While the impact on people caused by this event will be long lasting, the vast majority of the 28 ha living collection and core assets were not extensively damaged.

Bushfire at Blue Mountains Botanic Garden Mount Tomah, New South Wales. (Jaime Plaza van Roon)

Following the impact of the 2019 fires, the Garden has commenced a review of operations with a particular emphasis on water delivery systems and fire abatement infrastructure and planning for natural disaster recovery. We are also revisiting the surviving specimens to confirm their rarity and ensure priority genetics can be shared with other institutions with seeds to be collected and stored in our Australian PlantBank. Fortunately, gardens are dynamic and the loss of core collections has provided a chance to review our conservation objectives and refocus our efforts to replant collections aligned to our core mission, design more resilient landscapes and improve data collection and fire-resistant specimen tagging systems. Looking forward, we aim to replace lost specimens through acquisitions of provenance-based collections from local and international institutions.

Fire is an unavoidable aspect of the Australian landscape. If appropriately designed and resourced, our infrastructure, staff, landscape and living collection management practices and systems can assist to mitigate, but not remove, the risks to our core collections and improve the garden's resilience to natural disasters.

Fire at Mount Tomah, view from Blue Mountains Botanic Garden Mount Tomah, New South Wales. (Greg Bourke)

Regenerating Eucalyptus sclerophylla following fire at Blue Mountains Botanic Garden Mount Tomah, New South Wales. (Greg Bourke)

Water leak of the main Garden supply line following bushfire at Mount Tomah, New South Wales. (Greg Bourke)

CASE STUDY: **Managing fire at Yerevan Botanical Garden, Armenia**

Anahit Ghukasyan and Anush Nersesyan

Founded in 1935, Yerevan Botanical Garden of the Institute of Botany of the Armenian National Academy of Sciences, comprises an area of 80 ha and boasts a diverse plant collection from various biogeographical regions (Caucasian, East Asian, Eurosiberian and North American collections). Yerevan is located in an extremely continental climate zone, with the Garden exposed to severe weather variations, situated in a semi-arid zone on a thick layer of volcanic, tuff-stone. The Garden maintains major collections of the Armenian flora, whilst the Institute operates the Armenian Biodiversity Information and Education Center.

On 13 July 2019, a fire started in the area close to the 'Cascade' geographical collections, a southeast slope covered in dryland shrubs (such as *Paliurus spina-christi, Rhamnus pallasii, Amorpha fruticosa, Cotinus coggygria, Lonicera* sp., *Rosa* sp., *Swida* sp.) and trees (for instance *Robinia pseudoacacia, Fraxinus excelsior, Acer tataricum, Quercus* sp., *Ulmus* sp. and *Gleditsia* sp.). Some 4,000 individuals of shrubs and trees were burnt. The financial damage amounted to some AMD 1,495,000 (USD 3,000). The Institute and the Garden are very vulnerable to regularly occurring fires because of a lack of a proper irrigation and special fire fighting systems given the institution's limited budget. Only 40% of the 80 ha of the Garden are more or less irrigated with water supply starting late in June only. Since 2019, a drip irrigation system has been installed over an area of 5 ha of the tree park and a deep well pump has been fitted to provide a part of the Garden with water, whilst contractors have recently been refurbishing the irrigation system for 13 ha of the geographical collections.

The development of a disaster management plan and the provision of special equipment is urgently required. This will also include training in fire and other disaster management for the Institute and the Garden to avoid or sustainably manage future fires and other disasters.

Highly flammable dry scrub vegetation at Yerevan Botanical Garden, Armenia. (Joachim Gratzfeld)

SEVERE COLD, SNOW, FROST AND ICE

At the other end of the extreme temperature spectrum, botanic gardens are also faced with spells of severe cold, frost and ice, with nearly 60% of the survey respondents having experienced the damaging effects of these events in recent years. Although it is the prolonged periods of extreme cold weather that prove particularly detrimental to plants not adapted to cooler climates, even a single, short frost can destroy collections of tropical plants if protection cannot be ensured. Even in latitudes used to cold winters and heavy snow, botanic gardens have been experiencing more extreme climatic conditions than usual. For instance, many tree and shrub specimens at the Botanical Garden of Vilnius University, Lithuania were damaged or perished following three days of snow fall in 2021 accumulating some 600 mm of snow, whilst late frost ruined the spring blossom of many plants in its collections in 2017.

CASE STUDY: **Heavy snow at Jevremovac Botanical Garden, University of Belgrade, Serbia causes loss of an iconic beech tree**
Mira Fiskalovic and Marija Joncic

Jevremovac Botanical Garden of the University of Belgrade, Serbia was established in 1889. The area has a humid, continental climate.

On 11th January 2021, heavy snow caused the fall of a 160 year old *Fagus x moesiaca* (K.Malý) Czeczott (*Fagus × taurica* Popl.), one of the Garden's most emblematic and oldest trees. This has changed the part of the Garden where the beech grew permanently. In addition to the loss of the particular micro-climate in the immediate vicinity of this tree, it was a popular spot in the Garden both for staff and visitors to take pictures and rest. During the event, four other large trees were damaged. Furthermore, external support had to be called upon to secure the Gardens' administrative building as it had been affected too when the beech was uprooted.

This event has made the Garden's administration realise that a disaster risk management plan is needed, especially as its collections feature a number of other centenarian trees. In addition, staff need training in disaster management planning and implementation.

The iconic beech (Fagus x moesiaca) at Jevremovac Botanical Garden, Serbia, uprooted following heavy snowfall. (Milan Veljic)

CASE STUDY:

Snow storm hitting the Real Jardín Botánico, Madrid
Esteban Manrique and Mariano Sánchez García

The Real Jardín Botánico in the city of Madrid, Spain, is part of the Spanish Scientific Research Council. The Garden was created in 1775 and has recently obtained the title of UNESCO World Heritage site.

In January 2021, Madrid was buried under the heaviest snowfall experienced in the last 50 years. Located in the centre of the capital, the Garden was especially affected accumulating snow up to a depth of 50 cm. The outdoor living collections were heavily impacted due to the weight of the snow and the freezing temperatures, causing breakage and fall of large branches - particularly from evergreen trees - and crushing plants below. Pine, cypress and cedar trees suffered the most. Fortunately only two specimens were lost forever, a hackberry and a carob tree.

During several days the temperatures didn't rise above -12°C, affecting plants from subtropical and tropical climates, especially palms, such as *Sabal domingensis* (Caribbean), *Brahea edulis* (Mexico) or *Livistonia decipiens* (Australia) and killing various individuals in the living collections. The economic impact of the damage has been estimated at more than EUR 300,000 (USD 355,670).

After an initial assessment of the situation the first measures to mitigate any risks for the staff working in the Garden were to prune any of the broken yet still attached tree branches. This was followed by clearing up fallen branches and debris from the Garden grounds and further restoration efforts over several months. Staff have also been involved in strategic disaster planning for better preparedness in the event of future disasters. The most important lessons learnt were: 1) not to grow pine trees on grass meadows under Mediterranean conditions; 2) a disaster management plan needs to take into account rare events like the one experienced; and 3) knowledge and in-depth understanding of tree care and maintenance is essential, and primary tools like chainsaws need to be made available at more than just one location in the Garden.

Below: Subtropical collections left damaged following cold spell and snow storm at the Real Jardín Botánico, Madrid. (Mariano Sánchez García). Bottom: Heavy snow, a rare event at the Real Jardín Botánico, Madrid. (Mariano Sánchez García)

STORMS

Powerful storms – hurricanes, cyclones, typhoons and tornados – are amongst the most commonly experienced disasters that strike botanic gardens, with over 31% of respondents reporting such incidences (Figure 2). Although hurricanes, cyclones and typhoons generally form over tropical and subtropical waters, land-borne thunderstorms and tornados also represent potent hazards. Gardens located on tropical islands are frequently at risk from their destructive effects including associated heavy rains, hail and lightning, causing floods, landslides, fire, etc. Many of the institutions established in areas that are regularly hit by powerful storms, have learned to live with these events and have devised practices to moderate disaster impact on personnel, collections and infrastructure.

Joseph Reynold O'Neal Botanic Gardens, British Virgin Islands, in 2017, following Hurricane Irma. (top: T. Dawson; bottom: National Parks Trust of the Virgin Islands)

CASE STUDY: **Joseph Reynold O'Neal Botanic Gardens, British Virgin Islands, experiencing two powerful hurricanes a couple of days apart**
Nancy Woodfield Pascoe
and Cassander Titley-O'Neal

Joseph Reynold O'Neal Botanic Gardens are located in Tortola, British Virgin Islands. The 2.87 acre tropical urban garden was established in 1979.

In 2017, the British Virgin Islands suffered two Category 5 hurricanes, Irma on 6th and Maria on 17th September. The Garden lost 90% of its trees, many of which had been planted in 1979 when the institution was founded. All the buildings except for a small gift shop were destroyed, including the nursery where the threatened plant collection was housed, and many specimens were lost. Tools and equipment were looted as soon as Hurricane Irma had passed. The Gardens had a disaster management plan in place but the catastrophic damage caused by these extreme events could not prevent the level of damage. National Parks Trust of the Virgin Islands (NPTVI) staff and volunteers worked tirelessly to clear building debris and fallen trees, in order to make the site safe.

Since 1998, NPTVI and the Royal Botanic Gardens Kew (RBGK), United Kingdom (UK), have maintained a partnership to support research and conservation activities in the islands. In January 2018, RBGK scientists visited the Gardens to assess the impact and assisted the NPTVI team by sending arborists to prune the many fallen and damaged trees. Another UK partner, the Royal Society for the Protection of Birds, also assisted NPTVI by donating a hurricane relief grant to replace the damaged tools.

The lessons learnt from these extreme events are the importance of having and following the institution's disaster management plan to secure threatened living collections, tools and equipment. On this occasion, some of the rarest plants were stored in the basement of a stone structure that survived; this is a useful practice and will be replicated in future events. Looting was an unforeseen event in the Gardens as this had never been experienced before and is now included as a potential threat to be managed post-disaster. Training of new staff in tree pruning as a preventative measure is essential as the Gardens have only one professional arboriculturist within their team, as is storing a well-maintained supply of pruning equipment including chainsaws and blades.

CASE STUDY: **Severe cyclone hitting Auroville Botanical Gardens, India**
by Paul Blanchflower

Founded in 2000, Auroville Botanical Gardens is located in Tamil Nadu, southeastern India, close to the Indian Ocean in a region with monsoonal climate. On 31 December 2011, cyclone Thane hit the Garden. Established for only 10 years, the majority of the Garden's plants that were lost were the exotic tree *Acacia auriculiformis*, growing as a restorative pioneer on the land which had previously been barren. 80% of these trees fell, in addition to other large specimen trees in the arboretum. There was extensive damage to infrastructures, including the nursery. Overall, 12 buildings suffered damage to the roofs, solar panels and the water pumping windmill. The estimated loss was over USD 5,500 in damages to infrastructure and another USD 5,500 in cleanup costs.

Over the following six months, all of the roofs and other infrastructure were repaired. It took 24 months for all of the fallen trees to be cleared and the Gardens to be restored. We were very lucky in that we received donations amounting to nearly USD 7,000 to cover the repairs and cleanup from philanthropists connected to the Gardens.

The main lesson learnt from this event was that these kinds of storms will be inevitable in the future, and that our plantation patterns within the arboretum must allow for this reality. We need to have a mixed age plantation, as the larger trees will always be more vulnerable to the strong winds. So we now aim to have three to four of each important specimen, and plan to plant at least one specimen of each species every ten years or so. In terms of training, there is now a checklist of items to attend to when severe storms are approaching with respect to the infrastructure: we tie up the windmill and double check the solar panels etc.; we are also better equipped now that the Gardens are more developed, and have backup generators for the water pumps, etc. Tree maintenance is also important to ensure the crown is well balanced, and any damaged limbs are removed.

Auroville Botanical Gardens, India, following cyclone Thane in 2011. (Paul Blanchflower)

It was clear from the storm damage, that the native species of this area are adapted to this kind of weather pattern, and that many of the exotics are not. The shallow roots of *Acacia auriculiformis* are a classic example of how trees without experience of high winds in their natural habitat (Northwest Queensland, Australia) may have beneficial effects as short term pioneers, but in the long-term, they are a liability in this kind of severe event.

A rare specimen of 'Zope Negro' (Vatairea lundellii) uprooted in the 2017 storm at Jardín Etnobiológico de las Selvas del Soconusco, Mexico. (Anne Ashby Damon)

CASE STUDY:

Jardín Etnobiológico de las Selvas del Soconusco, Mexico, at the centre of a powerful storm, or "tromba"

Wilber Sánchez Ortiz
and Anne Ashby Damon

The Jardín Etnobiológico de las Selvas del Soconusco, extending over one hectare at an elevation of 80 m above sea level, is located in Chiapas, Mexico. This is a region with a tropical, humid climate and a short, but increasingly variable dry season, with an annual precipitation of approximately 3,800 mm. There are frequent thunderstorms.

In July 2017 the Garden was at the centre of a short and powerful whirlwind ('tromba'), with very localized, high winds of short duration (<10 min) causing major destruction. Thankfully human lives were not lost at the Garden but several months were required to remove fallen trees and debris. The storm severely affected the living collections, with 12 of the tallest, oldest and most iconic trees uprooted, including a 'Marillo' (*Calophyllum brasiliense, Calophyllaceae*), as well as a more than 30 m high 'Zope Negro' (*Vatairea lundellii, Fabaceae*) which was the only specimen of this species recorded in a botanic garden in Mexico. Although the tree remained alive for a further four years, vegetative propagation attempts using the trunk's side shoots were unsuccessful and the tree finally died in July 2021. The epiphyte collection was also badly affected by the storm with many specimens lost under a thick layer of debris. Clearing and repair of the buildings amounted to some MXN 100,000 (USD 5,000). Financial assistance was provided by the research center ECOSUR (MXN 20,000 (USD 1,000)) in addition to a donation of tools from a local hardware shop. Restoration work included planting of bamboos in the area affected by a landslide, reinforcing the river banks with local stones, and using wood debris to create terraces. These efforts were supported by a local community group interested in promoting agro-ecological practices in exchange for training in soil conservation techniques.

Recovery efforts at the Jardín Etnobiológico de las Selvas del Soconusco, Mexico, following the 2017 storm. (Anne Ashby Damon)

The clearance of vegetation has brought opportunities to expand the living collections in a more strategic manner, with greater representation of the local plant diversity of Soconusco. Propagule collection and propagation have been scaled up and some areas in the Garden have been left to be recolonized naturally. The development of an institutional disaster management plan has now been prioritized, which should address the duplication of rare and threatened species in another site or institution, as well as training of staff to manage disaster events. The Garden is planning a series of training workshops on tree health, pruning and the use of climbing equipment.

CASE STUDY:

Storm hitting Batumi Botanical Garden, Georgia

Zurab Manvelidze and David Kharazishvili

Situated on the Black Sea north of the city of Batumi, Georgia, Batumi Botanical Garden was established in 1912 by the botanist and geographer Andrey Krasnov. The Garden has a highly humid and subtropical climate, and extends over 111 hectares with a flora from nine phyto-geographic regions. In particular, three hectares of Colchic forest remain, a temperate broadleaf and mixed forest type along the eastern and southern shores of the Black Sea. The United Nations Educational, Scientific and Cultural Organization (UNESCO) added the Colchic Rainforests and Wetlands to the World Heritage List in July 2021 to recognise the uniqueness and conservation urgency of this forest type. Related species growing in the Garden include *Buxus colchica, Castanea sativa, Fagus orientalis, Laurus nobilis, Osmanthus decorus, Ostrya carpinifolia, Pterocarya pterocarpa, Quercus hartwissiana, Quercus imeretina, Quercus pontica, Rhododendron smirnowii, Rhododendron ungernii, Staphylea colchica, Taxus baccata, Ulmus glabra* and *Zelkova carpinifolia*. A number of exotic species have invaded the steep slopes of the Garden including the climber *Pueraria lobata* originating from East Asia.

Invasive climber Pueraria lobata (Fabaceae) in Batumi Botanical Garden, Georgia. (Zurab Manvelidze)

A severe storm hit the Garden in May 2014, resulting in major losses to the living collections. 36 woody plants representing 27 species were lost whilst a further 50 specimens were badly damaged. Fortunately, no people were injured and the Garden's infrastructure was not affected. Batumi Municipality City Hall and Cartu Foundation provided financial support to recover the collections following the storm. Disaster management is included in the charter of Batumi Botanical Garden and there is a dedicated staff trained in health and safety.

CASE STUDY: **Winter and ice storms at Oklahoma City Zoological Park & Botanical Garden, USA**

Christopher B. Hoffman

Oklahoma City Zoological Park & Botanical Garden was established in 1904 and moved to the current location at 2000 Remington Place Oklahoma City, Oklahoma, United States of America in 1924. The climate is temperate, humid subtropical, with 36 inches (900mm) annual precipitation and a history of weather extremes.

From 26-28 October 2020, the region was hit by an ice storm with accumulations up to 2 inches and designated a 'natural disaster' by the Government. This was the first time the National Weather Service issued an ice storm warning in the month of October for Oklahoma. The impacts in the Garden included major damage to upper and mid-level tree canopies. Maintaining heat to facilities, including two greenhouses, by generators was the priority during power losses. Impact assessments began immediately as the ice storm ended with an initial focus on health and safety of access routes and damage to facilities which proved to be minimal. An 'all-call' resulted in 60+ staff members helping the initial cleanup effort for a partial reopening two days later. A second intensive cleanup effort lasted 3.5 weeks involving a collaborative approach, with contractors focusing on tree arbor care and our staff providing labor and equipment to load and haul debris.

From 7-20 February 2021, the region experienced two Category 3 winter storms with arctic air outbreaks. A record cold temperature of -15 F (-26 C) was logged on the 16th of February, the coldest temperature since 1899 and second coldest on record. With temperatures below 20 F (-6 C) for six days and 14 days straight below freezing, a state of emergency was declared, and all Oklahoma counties were designated as a federal disaster area.

Preparation for extreme weather events includes active monitoring of weather forecasts and regular team updates. Winter storm supplies are ordered and stocked prior to events. The unique relationship of a zoo and botanic garden comes with a particularly high level of care. As such, skeleton staffing alternated in overnight stays to monitor facilities. Early contact was made with contractors to line up equipment and crews. City Parks & Recreation crews hauled off an estimated 100 tons of debris. Additional stressors for staff were related to extended power outages, damage to their own properties and poor travel conditions. Health, safety and welfare for staff, animals and guests remained the priority. A higher level of arbor care was provided at primary use areas, for three 'Champion Trees' and remnant trees of the Cross Timbers Ecosystem. Greenhouses holding tropical and cacti collections, overwintering and propagated plant materials as well as 4,000 annuals for seasonal color suffered no losses. On site, however is a different story, and with 120 acres, Mother Nature will be our partner in recovery over the next decade.

Oklahoma City Zoological Park & Botanical Garden following the winter storms in 2020. (Christopher B. Hoffman)

Existing relationships with city partners, contractors and volunteers proved invaluable in cleanup efforts. A *safety first, patience second* approach has given time to gauge which plant materials were truly damaged. The experience itself proved a catalyst in real-world training for future events.

Oklahoma City Zoological Park & Botanical Garden following the winter storms in 2020. (Christopher B. Hoffman)

FLOODS

Generally brought about by torrential rains but also by rising sea levels, earth-and seaquakes, floods, inundations and landslides represent other, frequently recurring events that botanic gardens are increasingly having to deal with. Flash floods may sweep away garden infrastructures and wipe out entire collections within seconds but, equally, standing in or under water for days and longer can be hazardous or lethal to any plant, as the composition and quality of the water itself (e.g. muddy, acidic, alkaline, brackish or saline) can cause plants to perish in the short or long-term. Moreover, botanic gardens situated in coastal areas are more and more at risk of rising sea levels. Although these are not expected to be uniform everywhere on Earth, current projections predict average sea level rises of 3.6 mm per year (IPPC 2019).

Flooding increasingly affecting the Royal Botanic Garden Sydney. (Scott Jones)

CASE STUDY: **Rising seas levels affecting the Royal Botanic Garden Sydney, Australia**
David Laughlin

The Royal Botanic Garden Sydney (RBGS) was founded in 1816 and is one of three botanic gardens and the Domain that make up the Royal Botanic Garden & Domain Trust (RBG&DT). Located on the east coast of Australia the climate is humid subtropical with mild and cool winters and warm hot summers experiencing high humidity in the months of January and February. RBGS is heavily influenced by its topography as part of the southern foreshore of the iconic Sydney Harbour. The Garden is located within the geological formations of Hawkesbury Sandstone Alluvium with some residual influence of the Wianamatta Series on its higher elevations. A large section of the lower garden is land reclaimed through three major phases of reclamation (1848/50, 1855/58 and 1867/78) with the building of the heritage-listed sea wall around Farm Cove adding almost 5 hectares to the Garden. While potentially susceptible to a range of threats, a key risk to RBGS is inundation of the lower reclaimed garden due to flooding, king tides and rising sea levels.

Flooding increasingly affecting the Royal Botanic Garden Sydney. (Scott Jones)

Currently the lower garden receives moderate flooding when Sydney is subject to major rain events known as an east coast low. When the east coast low coincides with a king tide the damage to the lower garden is significant. As the sea level rises, these major flooding events seem to be more frequent. There is major damage to lawns with water not draining away for several days. Large annual displays have been decimated and events such as weddings affected. The major impact is on our established trees and perennial collections in the lower garden. There are many highly significant trees that may be impacted by even a slight rise in sea levels. The most iconic is a *Ficus macrophylla* known as the Children's Fig planted under the directorship of Charles Moore 1848 – 1896. There are also significant collections of Myrtales, palms and oriental plants with a small collection of New Zealand flora potentially affected.

Climate change, leading to sea level rises will inevitably lead to increased frequency of inundation events, greater damage to the living collection and an increased accumulation of salt in soils. While fundamentally this is catastrophic for the salt sensitive species in our living collection, it is equally harmful to our fixed assets and revenue streams due to decline in quality of infrastructure and event spaces which derive significant revenue for the upkeep of the Garden.

The RBG&DT continues to maintain the heritage listed sea wall which acts as a barrier to Harbour wave activity and mitigates some of the impacts of the king tide events. Raising the heritage-listed sea wall height is currently not a viable option with current consideration given to raising the level of individual garden beds and collection succession planning especially for long-lived plants such as trees.

RBG&DT has developed a Climate Change Risk Assessment which identifies key risks to assessing future climate change hazards including the risks, likelihood and consequences. This includes a review of the adaptation or mitigation strategy effectiveness, the need for additional strategies to be formulated, and opportunities for future strategic adaptation which remain under development.

LANDSLIDES

Landslides were identified as a threat by about 6% of respondents to BGCI's survey, and are generally the consequence of heavy rainfall combined with susceptible topographies and soil or geology.

CASE STUDY: **Landslide at the Jardín Botánico de Popayán, Colombia**

Ivonne Andrea Zambrano, Carlos Andrés Durán Enríquez and Luis Gerardo Chilito López

Founded in 1997, the Jardín Botánico de Popayán, municipality of Timbío, Cauca, Colombia is located at the Los Robles headquarters of the Popayán University Foundation. Situated at some 1,850 m above sea level, the Garden has a temperate climate.

In 2013, a land mass movement engulfed the Garden affecting one of the trails in the Mano de Oso area, with a part of a large slope covered in vegetation collapsing and causing serious damage to the waterfall, one of the most attractive sites of the Garden. Access became impassable and the area had to be closed for more than a year to avoid accidents. Due to the geomorphology of the terrain and limited economic resources, the Garden could not carry out any restoration work and the site was left to a process of natural regeneration.

This event highlighted the need for a disaster management plan to mitigate damage caused by future hazards and improve recovery action. This includes identification of the areas most at risk within the Garden, and dissemination of the plan to all staff.

Mano de Oso cascade before the landslide in 2013. (Mariem Rocío Ibarra)

Landslide on the Yungas road (Camino de la Muerte), Bolivia. (Noelia Álvarez de Román)

EARTH- AND SEAQUAKES, AND VOLCANIC ERUPTION

About 8% of the respondents to BGCI's survey had experienced earthquakes and seaquakes, and just one garden reported exposure to a volcano. Gardens situated in areas of seismic disturbance are especially prone to such disasters, however, preparation time is often minimal and, of course, events of this nature can be cataclysmic for the gardens concerned.

CASE STUDY: **Wellington Botanic Garden ki Paekākā, New Zealand and the Kaikōura earthquake 2016**
David Sole

Wellington, New Zealand, is located on a natural harbour on the edge of Cook Strait, with the Wellington Botanic Garden ki Paekākā situated adjacent to the Central Business District. The area has a temperate but windy climate. Dubbed the 'shaky isles' by early settlers, Aotearoa New Zealand has many earthquakes, some of them significant and causing serious damage. In 2016 there was a magnitude 7.8 earthquake at 01:30 am at the north east of the South Island and centred about 180 km south of Wellington.

While Wellington did not suffer the obvious and scale of damage Christchurch experienced in 2011, it did take some time for the damage to become apparent. Once the initial assessments had been undertaken, Wellington Botanic Garden staff were able to return to work, the cafe reopened and garden visits could continue. In follow up assessments, five historic buildings were designated earthquake prone (complying with less than 33% of the National Building Standard – NBS). Two other major buildings had already undergone seismic strengthening before the earthquake. There was minor cracking of concrete at the Treehouse and cracking of a few panes of glass in the Lady Norwood Begonia House. It would have been much worse without the earlier remedial works.

Outwardly, the consequences of the earthquake were not obvious. In one building the ring beam around the top of the walls had multiple structural cracks, with seismic assessments showing that a chimney had started to separate from its building, and in another, it was identified that there was potential for liquefaction and building collapse where a road had been built on fill over an old stream system. The remaining buildings require seismic bracing to bring them up to 67% of the NBS. We anticipate the remedial works will cost between NZD 150,000 and 200,000 (USD 105,000 and 140,000).

As part of the Parks, Sport and Recreation Business Unit of Wellington City Council there was a Business Continuity Plan (BCP) in place which guided the response to the earthquake. Call trees were in place and activated, initial site assessments were undertaken by senior managers and followed by structural assessments by engineers. As the event occurred at night, emergency assembly and evacuation plans did not need to be activated.

Cracked chimney of the gardeners' depot and separating from the building at Wellington Botanic Garden, following the Kaikōura earthquake in 2016. (David Sole)

Less tangibly, and despite the lack of visible damage, the earthquake had a significant emotional impact on many of our staff. They were concerned about their safety in the buildings, the undertaking of initial damage assessments by managers and of the uncertainty the earthquake engendered.

The key findings from the event were: 1) A scalable Business Continuity Plan (BCP) is essential and should cover natural disasters as well as significant events that will affect the business (fire, IT failure, drought, infrastructure failure, pandemic); 2) The BCP did work but understated the need to attend to the welfare and concerns of the staff; 3) The consequences of this event to our buildings were long-term and not immediately understood at the time; 4) It reinforced the need for good emergency response planning and regular evacuation drills; 5) While this event appears comparatively minor when read against more severe earthquakes, widespread flooding and cyclones it does illustrate that all events – small or large – have consequences for people and infrastructure and these should not be underestimated.

CASE STUDY: **Andromeda Botanic Gardens, Barbados covered by ash**
Sharon Cooke

Andromeda Botanic Gardens is a 6.5 acre tropical garden situated near the east coast of Barbados. The Gardens were created from the 1950s as a private botanic garden, by Iris Bannochie – a multiple award-winning gardener, scientist and horticulturist.

The major recent disasters were the COVID-19 pandemic and the ash from the eruption of La Soufrière in St Vincent, located approximately 170 km (100 miles) to the west of Barbados. Both disasters caused temporary closures, income reductions, loss of jobs and damage to collections.

After losing an entire year's income, approximately BBD 300,000 (USD 150,000), due to the pandemic, on 9 April 2021 La Soufrière volcano erupted in St Vincent. On 10 April, the day of our first ever online workshop, the ash started falling on Barbados and we descended into darkness. It was surreal. On 11 April, the Gardens looked apocalyptic and the task of recovery seemed overwhelming. We closed yet again. The five-week closure caused a loss of about BBD 8,000 (USD 4,000). While small compared with COVID-19, we had no resources left and we had to lay off our only staff member. Financially we had just about survived the pandemic but the ash was simply too much for our tiny business to bear, without making sacrifices.

We had no guidance but decided that the first task was to remove the ash from the leaves and buildings as quickly as possible. The inability of plants to photosynthesize was my main concern and I did not consider the possibility of ash-burn on the leaves. Many seedlings failed; many established plants were severely damaged; and many were fine. We sprayed ash off as many leaves as we could, using hoses. We repeated this three times over a period of three weeks as ash was still being deposited. Thankfully, it rained. Although the rain was not enough and the ash was still here, it was nothing like it was before.

One lesson learnt is the importance of ensuring all infrastructure is in working order. A huge section of our water supply was unusable due to broken pipes. Had it not rained, there would have been considerably more damage to plants. There is a need to ensure a certain percentage of income is reserved for disasters such as these. That reserve, probably BBD 100,000 (USD 50,000) will be held in a separate account. It is a huge chunk of our income but having such funding would mean that people would keep their jobs; we would be able to keep Andromeda Botanic Gardens maintained; bills would be paid; and we would survive as a business. We did not have that cushion and we have appealed for funds using GoFundMe, the local press, our own social media, and various other ways to raise money. While we have not mobilised as much as we would like, these contributions from donors as well as local visitors have kept Andromeda Botanic Gardens maintained and open.

Andromeda Botanic Gardens in Barbados before, and after being covered by ash from the La Soufrière volcano. (Sharon Cooke)

SOCIAL UNREST, ARMED CONFLICT AND WAR

At the extreme end of disasters experienced by botanic gardens is social unrest, armed conflict and war. Although these events are comparatively rare, two of the respondents to our survey had experienced this kind of disaster and, of course, lower level security threats are unfortunately still common in many gardens – particularly those situated in less affluent urban neighbourhoods.

Conservatory at Donetsk Botanical Garden, Ukraine, hit by bombshells in 2017. (Tatyana Nikulina)

CASE STUDY: **Impact of armed conflict and war on Donetsk Botanical Garden, Ukraine**

Tatyana Nikulina

Founded in 1965, Donetsk Botanical Garden is situated in the city of Donetsk, Ukraine. Since 2014, this territory is part of the Donetsk People's Republic. The climate is continental. Living plant collections include specimens of 8,000 species, varieties and cultivars.

Since 2014, the territory of southeastern Ukraine has been a zone of armed conflict, and economic and political isolation. This has also had damaging impacts on all botanic garden activities. Before the outbreak of war, the Garden's research personnel included six PhDs and 36 Masters candidates in Biology. Despite threats to life which caused some staff to leave, the majority of personnel have continued working for the botanic garden and maintaining the living plant collections.

Damage to the Garden's infrastructure (glasshouses, administrative buildings and laboratories, equipment, etc.) and to the plant collections (especially loss of tropical collections due to sharp drop in temperature in the glasshouses) during the bombing on 12 February 2015 and explosion on 2 February 2017 is estimated to range between RUB 16,681 (USD 225) and RUB 243,400 (USD 3,280).

Despite the threats to life and lack of funding in the years 2014-2015, regular collection maintenance work did not stop, and all main research activities continued. Currently, the botanic garden operates in the Donetsk People's Republic and is state-funded. Before 2014, we didn't have a strategy in the event of an armed conflict as no such precedents had been experienced for the entire period of the Garden's existence. Public organizations and individual benefactors provided support in resolving the impacts of the shelling, and we also received humanitarian aid. Yet, botanic garden personnel play a crucial role in mitigating the impacts of the war, as they continue with urgent repairs to damaged greenhouses and laboratories, and also as they protect the tropical and subtropical plant collections from the impact of sharp temperature drops as a result of the damage to the polycarbonate coating and glazing structure.

The development of an effective countermeasures strategy has been a difficult undertaking. Shelters for employees have now been set up, and information signs for visitors have been installed. Work was carried out to train personnel in providing first aid. A reserve of roofing materials has been obtained for the prompt repair of the greenhouse complex. A database of organizations and individuals capable of providing urgent support has been set up. To acquire additional funds for institutional development and urgent needs, the garden staff actively engage with the public to promote the Garden as an attractive venue for visitors, organizing site excursions, and offering educational and entertainment activities.

Protection of tropical and subtropical plants from a sharp drop in temperature resulting from the damage to the polycarbonate coating of the conservatory caused by the bombshells. (Alexandra Nikolaeva)

MULTIPLE HAZARDOUS EVENTS

Many of the respondents to our survey reported experiencing multiple disasters – sometimes simultaneously or in rapid succession – stretching their resources and resolve to the limit.

2010 wildfire at Jardim Botânico Araribá, Brazil. (Guaraci M. Diniz Jr.)

CASE STUDY: **Droughts, fires, floods and the pandemic at Jardim Botânico Araribá, Brazil**
Guaraci M. Diniz Jr.

The Jardim Botânico Araribá, municipality of Amparo, São Paulo, Brazil, is part of the Duas Cachoeiras Private Natural Heritage Reserve (RPPN) which was recognised in 2021 by the United Nations Educational, Scientific and Cultural Organization (UNESCO) as an 'Advanced Post of the Atlantic Forest Biosphere Reserve'. Situated in an area of Atlantic semi-deciduous forest, the Garden has been hit regularly by natural disasters including droughts (2014, 2019, 2020), forest fires (1999, 2005, 2010, 2020) and floods (2011, 2012, 2017). These hazards have caused damage to the wild conservation areas as well as to the Garden's *ex situ* collections and infrastructure such as fences, gates and the trails. Whilst the Garden had to be closed temporarily during and after these events, the closure of the garden for more than 15 months due to the pandemic has been the longest ever, and is associated with a shortfall of 90% of the Garden's annual income, causing the layoff of employees and shutdown of maintenance activities. The financial loss caused by COVID-19 is estimated to be in the order USD 150,000.

Given its location in Atlantic semi-deciduous forest habitat, the management of the Garden is adapted to occurrence of drought and accumulation of abundant dry organic matter posing an elevated risk of fires. Since 2000, the Garden has had its own volunteer fire brigade and specific fire-fighting equipment, and maintains an annually updated protection plan for preventing and fighting fires. The Garden also works in close partnership with the state of São Paulo to manage the forest and reduce fire risk in the RPPN protected areas (Box 2).

Periodically, firebreaks are established throughout the Garden's perimeter, and training is carried out with the fire brigade; in so doing, the Garden has gained control over these hazards in recent years and the massively destructive effects of forest fires have been kept at bay to a large extent.

To prevent and mitigate the effects of droughts and floods, the Garden has also installed a system of rainwater reservoirs that serve as a source for irrigation, fighting fires and slowing down flashfloods, whilst allowing water to infiltrate into the soil to replenish the water table. This system will be further expanded over the coming years.

In response to the pandemic, the Jardim Botânico Araribá is in the process of redeveloping its visitor and environmental education strategies, specifically policing the ceiling of the total number of participants per activity. In addition, the public engagement programmes will consider a series of therapeutic activities to mitigate the physical and psychological effects brought about by the long period of social distancing and isolation.

Firebreaks in the Jardim Botânico Araribá, Brazil. (Guaraci M. Diniz Jr.)

BOX 2: 'OPERATION FIREBREAK' – MANAGEMENT OF FIRES IN THE STATE OF SÃO PAULO, BRAZIL

The state of São Paulo, Brazil established the State System for the Prevention and Fight against Forest Fires which aims to: reduce fires in the state; reduce greenhouse gas emissions from burning; protect areas with vegetation cover against fire; eradicate the irregular practice of the use of fire, respecting the provisions of State Decree No. 56.571/2010; and encourage the development of alternatives to the use of fire for agricultural, pastoral and forest management.

Operation Corta-Fogo, as the System is called, is formed by various state bodies such as the State Civil Defense Protection Coordination, the Fire Department, the Environmental Military Police, the Environmental Company of the State of São Paulo, the Forest Foundation and the Forest Institute. The coordination of the system is carried out by the State Secretariat for Infrastructure and Environment, through the Coordination of Inspection and Biodiversity. To achieve its objectives, Operation Corta-Fogo develops a series of activities on a permanent basis throughout the year, being divided into phases (Green, Yellow and Red) according to the needs and priorities that each period requires:

Green phase –
January to March; November and December:
The green phase of Operation Firebreak is divided into two stages. The first stage, between the months of January and March, is dedicated to planning activities and starting prevention and preparedness measures. At the end of the year (November and December) an assessment of the fire season is carried out and preparations for the following year are started.

Yellow phase –
April and May:
The yellow phase requires a focus on preventive and preparedness actions to face forest fires. During the months of April and May, training, qualification, preparation and review of preventive and contingency plans activities gain priority.

Red phase –
June to October:
Between the months of June and October, the red phase of the Operation is activated. Firefighting and repressive inspection actions are prioritized and communication strategies and preventive campaigns are reinforced.

FASES DA OPERAÇÃO CORTA-FOGO

JAN	FEV	MAR	ABR	MAI	JUN	JUL	AGO	SET	OUT	NOV	DEZ
FASE VERDE			FASE AMARELA		FASE VERMELHA					FASE VERDE	

FASE VERDE (JAN–MAR):
- Planejamento das ações da temporada
- Início das ações preventivas e de preparação

FASE AMARELA (ABR–MAI):
- Intensificação das ações preventivas e de preparação

FASE VERMELHA (JUN–OUT):
- Maior atenção para ações de resposta
- Combate ao fogo
- Intensificação da fiscalização repressiva

FASE VERDE (NOV–DEZ):
- Avaliaação da temporada
- Início do planejamento da temporada segunite

Source: https://www.infraestruturameioambiente.sp.gov.br/cortafogo/

Jardim Botânico Araribá, Brazil following the wildfire in 2020. (Guaraci M. Diniz Jr.)

2012 floods at the Jardim Botânico Araribá, Brazil. (Guaraci M. Diniz Jr.)

CASE STUDY: **Floods and fires at the Harold Porter National Botanical Garden, South Africa**
Christopher Willis

The Harold Porter National Botanical Garden is one of the South African National Biodiversity Institute's (SANBI) ten national botanic gardens in South Africa, established in 1959, and located in the southwestern corner of South Africa. The area is dominated by natural coastal fynbos and Afromontane forest flora unique to the region, and forms part of the Kogelberg Biosphere Reserve. Of the 203 hectares of the Garden only ten are managed as landscaped or cultivated areas whilst the remaining 193 hectares are regarded as natural estate. The Garden is situated in montane and coastal fynbos vegetation and extends from the Kogelberg mountains onto the coastal plain towards the sea. Two rivers run through the Garden and come together in the cultivated portion of the Garden, becoming the Dawidskraal River that drains through a braided stream towards the sea.

The two natural disasters that the Garden is mostly exposed to are fires and floods, both of which have impacted the Garden in various ways. In the past 20 years, the Garden has suffered significant damage to its infrastructure through unusual flood events, the most recent having occurred in April 2005 and November 2013. The main damage resulted from cut-off lows or what are commonly known as 'black south-easters', occasional weather systems that deposit large amounts of rainfall over a short period of time. In April 2005, for example, 225 mm of rain fell in a 24-hour period. Extreme flood events have damaged bridges, pathways, roads, fences and parking areas. As regards fires, they form part of the ecosystem and natural processes in fynbos vegetation, triggering seed release, germination, flowering and removal of old and moribund vegetation. Fires have mostly burnt the natural areas of the Garden, including wooden bridges and irrigation systems which have had to be replaced. Funding support was provided by the national Department of Forestry, Fisheries and the Environment to SANBI and through insurance claims.

Harold Porter National Botanical Garden, South Africa, following the 2019 fire. (Christopher Willis)

Flood mitigation berm alongside the Dawidskraal River at the Harold Porter National Botanical Garden, South Africa. (Christopher Willis)

To manage the extreme flood events in the Garden, professional hydrologists and engineers were appointed to model the extreme flood events and develop appropriate infrastructural responses, both to guide future development projects as well as to contain and mitigate future similar disasters. As part of the Garden's environmental compliance to national environmental management regulations, a Maintenance Management Plan (MMP) was developed and approved by the responsible national government department. SANBI employs an external freshwater consultant to monitor and report on the Garden's implementation of the MMP. In response to the most recent extreme flood events, mitigation infrastructure was developed, including the installation of gabions and a flood diversion weir. The aim is to keep future floods within the river channel as well as diverting some of the downstream flows to historical channels. The Garden has also made efforts to source additional labour to assist in trimming and removing unwanted vegetation that may cause blockages in future flood events in the wetland and river systems that flow through the Garden.

The Harold Porter National Botanical Garden is also a member of the regional Fire Protection Association (FPA), and its staff have gained valuable experience and skill in fighting fires over the past two decades. There is a close working relationship with the local municipality as well as regional fire response teams and volunteers, and much support is received through the FPA when fires do occur. Controlled burns of natural fynbos should ideally happen every 12 years.

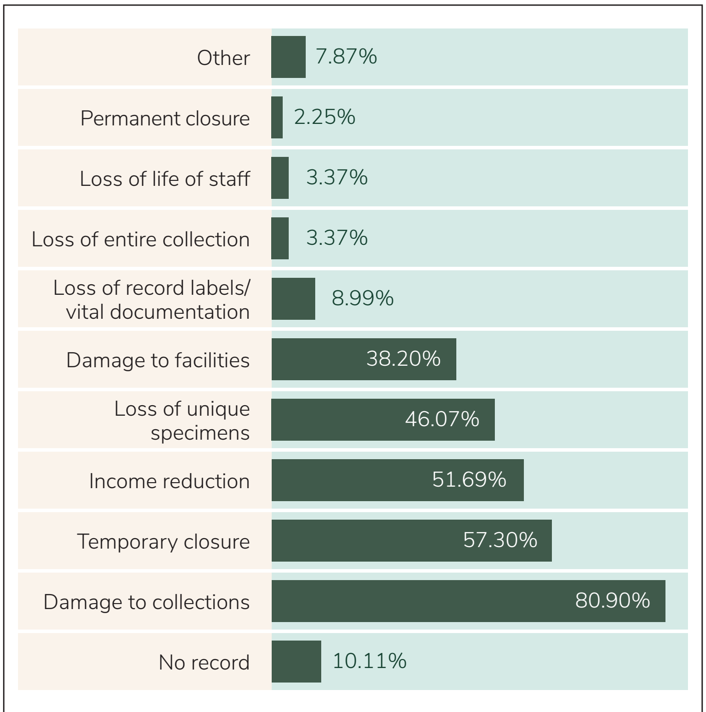
It is critical to understand the natural systems where a garden is located and respond in the most appropriate way possible, guided by best available research and ecological understanding, to prevent future negative impacts. Working closely with local authorities as well as neighbouring communities is essential, so that mutually acceptable and legislation-compliant responses can be implemented. SANBI maintains a chronological documented and photographic record of the impact of these major flood and fire events, and its responses, for the benefit of current management and future generations.

3.2 Disaster impacts

Botanic gardens are multifaceted institutions with plant collections, infrastructures, equipment and personnel, all of which may be affected by natural and man-made disasters. Figure 3 lists the most common impacts of disaster events.

Given the prevalence of extreme weather events, it is not surprising that over 80% of the respondents to BGCI's survey cite damage to plant collections as the main impact caused by disasters. Most of the case studies and survey responses bear witness of the damage to unique collections caused by fire, snow and ice, storm, flood, landslide or vulcanic eruption. For instance, Jevremovac Botanical Garden in Serbia lost its single *Fagus moesiaca* and one of the oldest specimens in the Garden to heavy snow in 2021. Joseph Reynold O'Neal Botanic Gardens in the British Virgin Islands lost over 90% of its tree collections to Hurricane Irma and Maria in 2017, whilst nine unique trees were toppled by Hurricane Irma at the Marie Selby Botanical Gardens, Florida. Unsuitable open-air collection locations not offering the ecological needs of species or inappropriate horticultural management, can make plants succumb more easily to disasters as can damaged greenhouse facilities that no longer provide for species-adapted climate regulation (for example case studies Real Jardín Botánico, Madrid and Donetsk Botanical Garden, Ukraine). Strategic collection planning, excellence in horticulture, plant recording and documentation, but also duplicating collections at various botanic gardens through a coordinated network of 'metacollections and global conservation consortia' (Box 3) offers an insurance policy against irrevocable loss (Gratzfeld 2016).

FIGURE 3: DISASTER IMPACTS EXPERIENCED BY RESPONDENTS TO THE BGCI SURVEY (N=89)



BOX 3: METACOLLECTIONS AND GLOBAL CONSERVATION CONSORTIA

Worldwide, over 3,500 botanic gardens maintain at least one-third of all known plant diversity in their living collections and seed banks. The collective conservation power of botanic gardens is essential to prevent plant extinction. Networks allow gardens to coordinate efforts to save endangered species and populations. Metacollections are the combined holdings of a group of collections. For gardens, metacollections are envisioned as common resources held by separate institutions but stewarded collaboratively for research and conservation purposes. Combining multiple collections into a single metacollection increases potential coverage within a group, allows broader access to greater diversity, dilutes risk of loss, and can reduce maintenance costs. The American Public Gardens Association's Multisite Collections, Botanic Gardens Conservation International's Global Conservation Consortia and the Center for Plant Conservation National Collection are established examples of metacollections. Like any collection, a metacollection can be of any scope or taxonomic level. "*Holding a critical plant collection at a single garden is no longer the best practice. As per the old adage, the best way to keep a plant is to give it away, gardens diminish risk of loss by distributing plants. Something as minor as an irrigation break or a change in management puts garden plants at risk, not to mention the havoc a wildfire or hurricane can bring! Keeping those plants at multiple locations reduces the likelihood of loss. Thus, the metacollection is the best way forward for conservation collections. Metacollections assure necessary redundancy, but also maintain diversity, minimize genetic drift from random losses, and reduce inbreeding*" (Griffith et al. 2019).

Roystonea borinquena metacollection at Montgomery Botanical Center, Florida. (M. Patrick Griffith)

The worldwide lockdown impelled by the COVID-19 pandemic has been the main driver of the other major impacts identified in the survey, including garden closure, loss of revenue and even loss of life. For the first time in the history of the global botanic garden community, gardens across the world have had to simultaneously close to visitors and wind down operations over a prolonged period of time, in many cases for more than a year. Temporary closure and associated losses in revenue (Section 3.3) unsurprisingly emerge as a potent impact, deeply affecting the resilience of botanic gardens (over 57% and 51% respectively of the survey respondents). *"The pandemic has reduced the Garden's income over the past year by at least 70%, resulted in a temporary closure, a reduction in hours and services, and all staff are on reduced hours"* (Red Butte Garden, Salt Lake City). With personnel reduced to a minimum, plant collections have also suffered from reduced horticultural maintenance as exemplified by the case study by the Jardín Botánico La Paz in Bolivia. However, any major disaster can potentially disable garden operations significantly, and cause it to close for a lengthy duration. The Conservatory of Flowers, San Francisco, remained closed for several years when it was hit and severely damaged in 1995 by powerful winter storms. Thanks to a public fundraising campaign mobilizing over USD 25 million, renovation work could be initiated, and the restored conservatory whose mission strives to connect people and plants, was reopened in 2003.

A number of other factors in the wake of a major disaster may compound an already precarious situation: for instance oil spills (Red Butte Garden, Salt Lake City); increase in soil salinity following inundation with sea water; pests and diseases requiring higher levels of biosecurity measures (Royal Botanic Garden Sydney and Royal Botanic Gardens and Domain Trust, Australia); greater susceptibility of collections to phenological changes and diseases as a result of drought, and disrupted pollination processes (Cadereyta Regional Botanical Garden, Mexico).

Sadly, several botanic gardens that responded to our survey have also experienced loss of life, with staff dying as a result of a disaster or the pandemic.

3.3 Disaster relief assistance and needs

The direct physical impact on people, plant collections and infrastructure but also the less tangible effects on mental health and wellbeing caused by natural and man-made disasters to botanic gardens vary enormously depending on the type, magnitude and duration of the events. In financial terms, the economic loss inflicted on gardens ranges from a couple of hundred US dollars to several millions. For instance, the pandemic is estimated to have caused the Jardim Botânico Araribá, Brazil, a shortfall of some USD 150,000, whilst damage by powerful storms to buildings and equipment of Joseph Reynold O'Neal Botanic Gardens, British Virgin Islands in 2017 amounted to some USD 600,000, and to the Conservatory of Flowers, United States of America in 1995, USD 5 million, respectively. In some cases, as in the example of Joseph Reynold O'Neal Botanic Gardens, just as the institution was recovering from longer term economic loss due to lack of income from renting out garden venues for events such as weddings, the COVID-19 pandemic struck.

Encouragingly, the majority of the survey respondents have reported that they have been provided technical and/or financial assistance following disaster events (Figure 4). Depending on locality and the type of disaster, financial support received ranged from USD 2,500 to some USD 5 million. Government is the most common source of aid with 61.1% of respondents receiving support from the public sector (Figure 5). Assistance was also extended by individuals (33.9%), voluntary groups (26.5%), corporates (23.5%) and NGOs (23%).

FIGURE 4: TECHNICAL AND/OR FINANCIAL SUPPORT EXTENDED BOTANIC GARDENS (N=89)

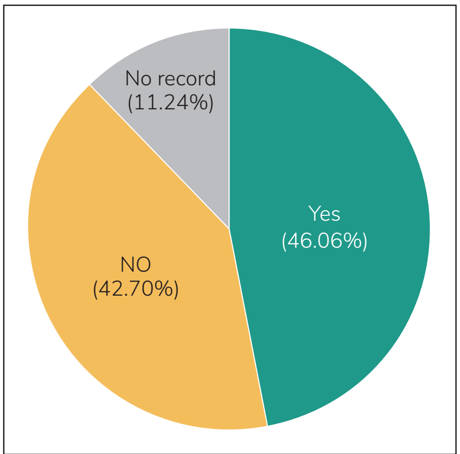
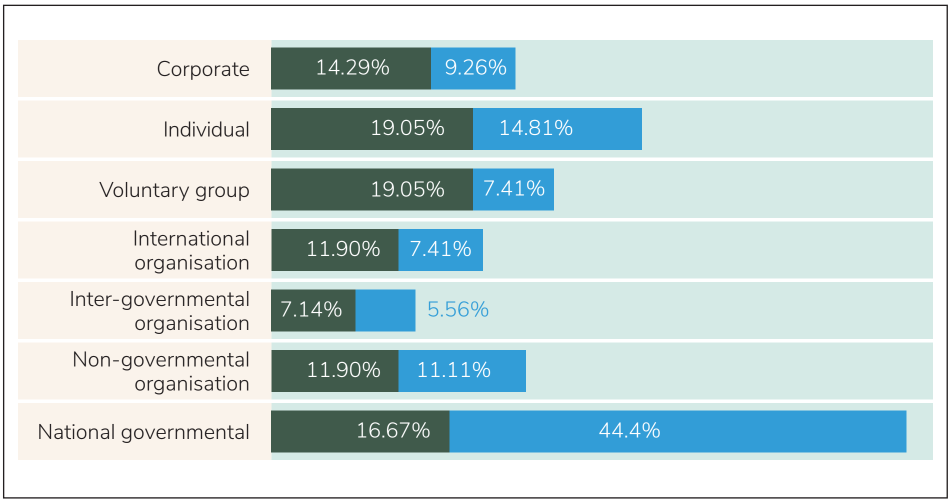


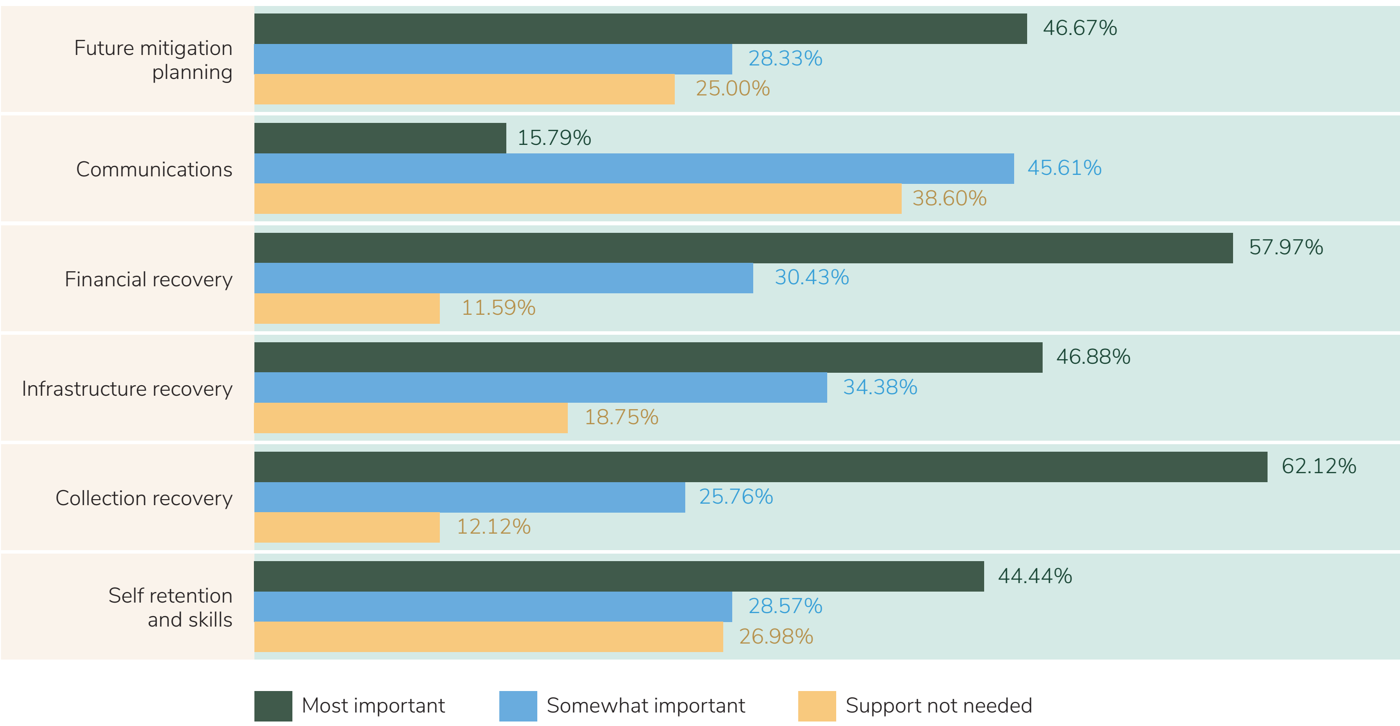
FIGURE 5: SOURCE OF TECHNICAL AND FINANCIAL SUPPORT (N=41)



Inundations at the Royal Botanic Garden Edinburgh, United Kingdom. (Royal Botanic Garden Edinburgh)

Collections and financial recovery are the two most needed forms of assistance highlighted by the survey respondents (Figure 6). In particular, this includes efforts to tidy up sites and collections such as removing fallen trees. Increased attention to arboriculture has proven to be very beneficial in some gardens to minimise the impacts of future storms (for example The Botanic Garden of Smith College, United States of America). Help is also sought to identify and approach potential sources of financial relief for recovery. Other areas where support is greatly needed include recovery of infrastructure (for instance reinstating the gardens' irrigation system or providing emergency energy units), followed by enhancing capacity for future disaster mitigation planning and retaining human resources and technical skills. Whilst many institutions have disaster management strategies or plans (Section 4), due to limited institutional budgets, gardens also report that *"it is almost impossible to implement them because of a lack of staff and financial resources"* (Cadereyta Regional Botanical Garden, Mexico).

FIGURE 6: AREAS OF SUPPORT MOST NEEDED (N=74)



3.4 Learning to manage disasters

The greater the recurrence of disasters, the more confident organisations become that they can respond to and manage future disasters, including droughts, wild fires, floods and storms (Figure 7a). As extreme weather events are becoming more common with climate change, so is our experience in managing them. Gardens also felt most confident about managing future pandemics. While the COVID-19 pandemic has not been a frequent occurrence, it has been widespread and prolonged, leading to significant management experience and "*handling the pandemic better than the town, county or state at this time*" as stated by one botanic garden.

On the other hand, botanic gardens are least confident about managing infrequent, catastrophic events such as war, volcanic eruptions and earthquakes (Figure 7b). However, even as botanic gardens' capacity to manage severe weather events is growing, one of the biggest challenges highlighted through the survey is long-term planning in the face of climate change. How can gardens mitigate the impacts of rapidly changing climate patterns on living collections over a 30-50 year horizon? Whilst this is one of the biggest questions faced by botanic gardens, the botanical community is stepping up to this challenge, realising that "In the next 50 years, 20-50% of current plant species in botanic gardens and urban landscapes will likely confront temperatures those species have never experienced before." (Dave Kendal, University of Tasmania). To this end, the Climate Change Alliance of Botanic Gardens was launched at the inaugural botanic gardens Climate Change Summit held at Royal Botanic Gardens Melbourne in 2018 (RBGV 2021). Amongst other things, the Alliance is working with BGCI to develop a Climate Risk Assessment Tool which is expected to provide support for botanic gardens to evaluate and manage the climate change threats faced by their living collections (Box 4).

FIGURE 7A: LEARNING TO MANAGE DISASTERS (N=82)

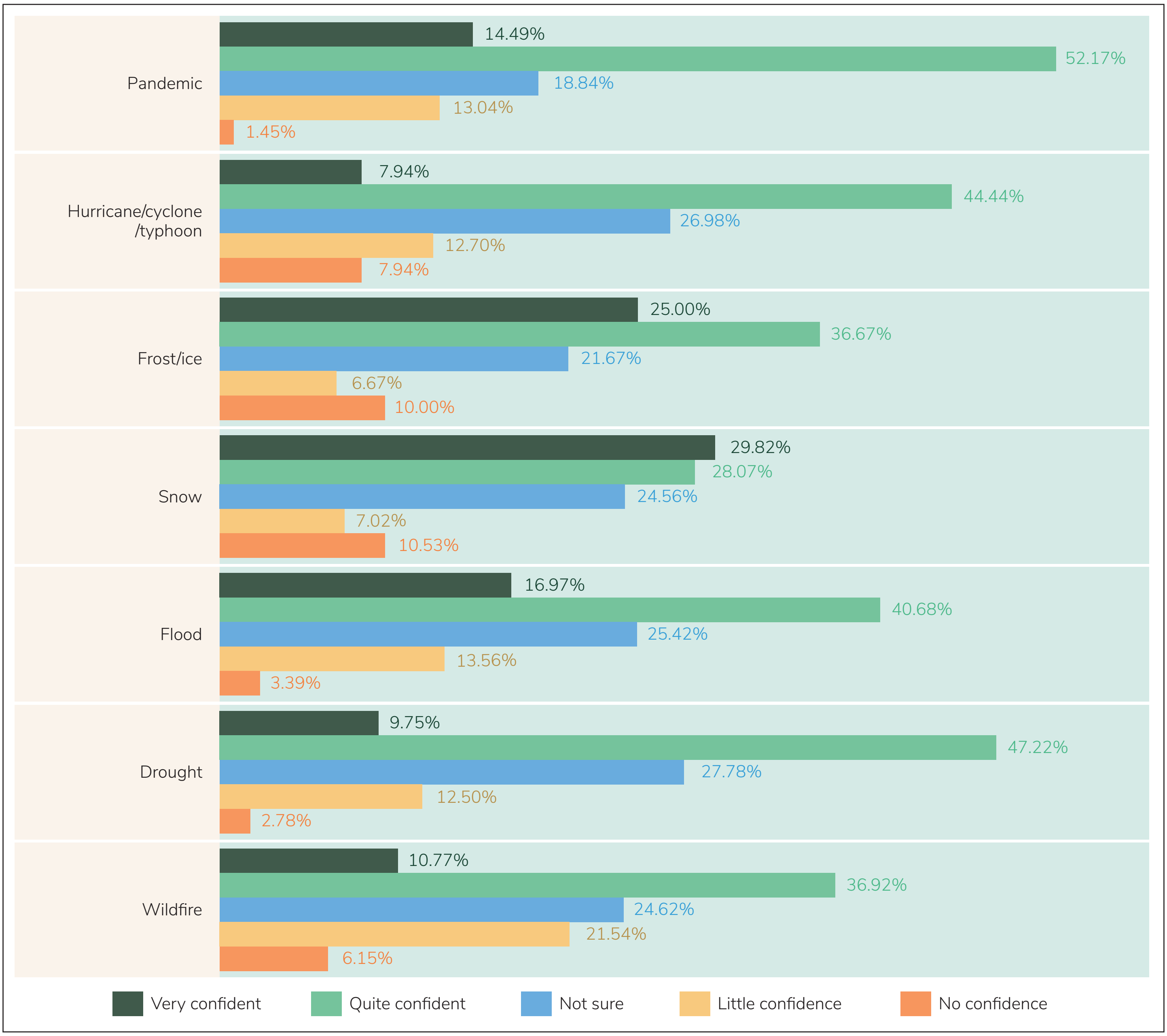
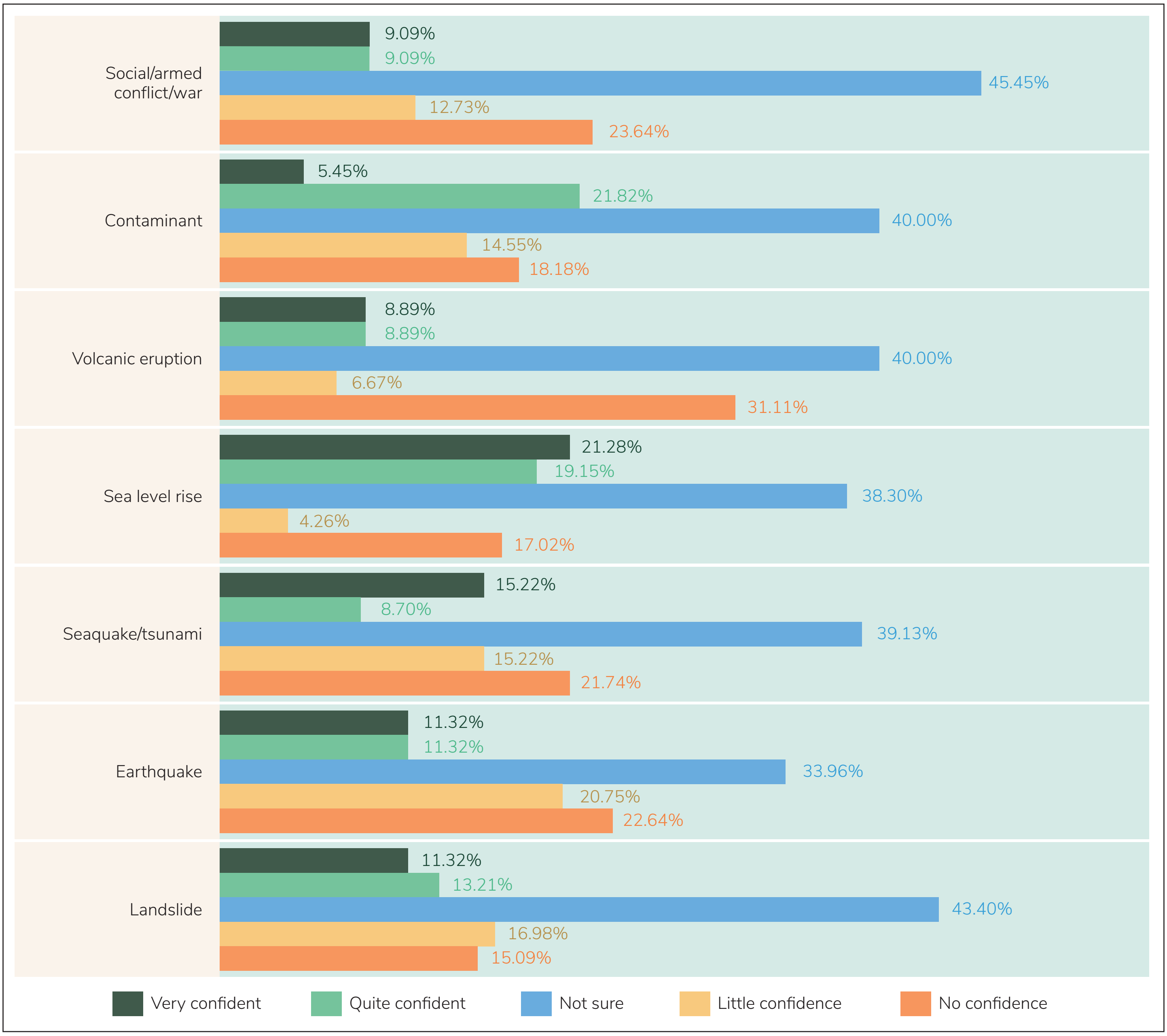


FIGURE 7B: LEARNING TO MANAGE DISASTERS (N=82)



Firefighters taking a break from battling wildfires at the Blue Mountains Botanic Garden Mount Tomah. (Greg Bourke)

Staff of the Jardín Etnobiológico de las Selvas of Soconusco taking a moment of reflection after the damage to the Garden caused by the storm in 2017. (Anne Ashby Damon)

BOX 4: THE CLIMATE CHANGE ALLIANCE OF BOTANIC GARDENS

In December 2018, people from a diversity of cultures, languages, and organisations from around the world attended the botanical world's first Climate Change Summit in Australia and formed the Climate Change Alliance of Botanic Gardens (the Alliance).

Since its formation, the Alliance has achieved the following:

- Agreed on an innovative Charter based on the adaptability and resilience of living systems such as the living landscapes and collections for which we are stewards
- Influenced positive action by governments, and energised botanical networks
- Developed the first iteration of a Climate Risk Assessment Tool (RBGV and BGCI 2021) to help manage plant collections and landscapes
- Delivered information and knowledge on effective climate responses and plant conservation at diverse forums and workshops
- Prepared a draft Landscape Succession Strategy Toolkit to support organisations in improving the resilience and sustainability of their landscapes through climate change.

By joining the Alliance, botanic gardens and similar organisations around the world will have access to a global network of botanic gardens and arboreta, botanic gardens associations, scientists, horticulturists and friends of Alliance who are working together to protect their gardens and the plants of the world. Through information sharing and increased influence, the Alliance will continue to be the change that the world needs to see.

Inundations at the Royal Botanic Garden Edinburgh, United Kingdom. (David Knott)

2020 wildfires at the Jardim Botânico Araribá, Brazil. (Guaraci M. Diniz Jr.)

CASE STUDY: **Managing changes in climate and weather patterns at the Royal Botanic Garden Edinburgh, UK**
David Knott

The Royal Botanic Garden Edinburgh (RBGE)'s living collection is cultivated in four gardens across Scotland each with different climatic conditions and all within 150 km of Edinburgh. Edinburgh is the driest with an average rainfall of 750+ mm, although this is increasing annually; Benmore in Argyll, western Scotland is the wettest with an average rainfall of 3,000+ mm rainfall and currently holds the record for being the 'warmest' garden at 30˚C. Logan in Dumfries and Galloway, south west Scotland is the mildest with air frosts in recent years being very uncommon with an average rainfall of 1,200 mm, and Dawyck in the Scottish Borders is the coldest with an absolute minimum of -20°C, with an average rainfall of 1,200 mm.

Changes in the climate and weather patterns over the last 30 years have created a number of challenges to the cultivation of the living collections across all four gardens. These impacts have included by Scottish standards drier springs, above average summer temperatures, higher autumn and winter rainfall levels, more intense rainfall events throughout the year, severe wind (over 160 km) and unseasonal cold spells. All of these affect plant growth and physical access to the plants in order to care for them. The only climate-change related impact, which we have not yet experienced, is a significant increase in temperatures (heat). Some of these changes in climate have been partially mitigated through horticultural practices including the use of mulches to conserve water, the installation of more effective drainage to reduce problems associated with a fluctuating water table and the installation of irrigation, rainwater harvesting and rain gardens. However, more importantly is using our Collections Policy and the careful selection and location of plants to ensure we have the right plant in the right garden and location within each garden in anticipation of what the future climate will be.

Perhaps the single greatest impact on the living collection in recent years was on the 3 January 2012 when 160 km winds caused extensive damage to the collections with a considerable number of trees uprooted across all four gardens. The most significant damage was to the research glasshouses in Edinburgh with significant structural damage and loss of glass. In July 2020, the Sottish Government granted GBP 50 million (USD 70 million) to RBGE to address the problems with these ageing buildings and glasshouses. Work is scheduled to start in 2021 to renovate the palm houses and public display glasshouses, replace the research glasshouses and construct a new plant health facility.

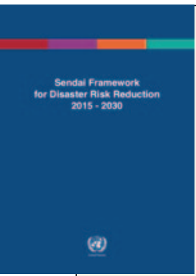
Storm damage at the Benmore Botanic Garden, United Kingdom. (Royal Botanic Garden Edinburgh)

Due to the increasing frequency of severe weather events over the last 30 years and the resultant damage to the living collection and infrastructure we now have horticultural staff trained in arboriculture and specialist machinery use in each of the four gardens. Resources and knowledge including details of specialist suppliers and machinery hire companies are shared to help ensure priority areas can be cleared and repaired quickly. Since 2012, an RBGE Emergency Response Group, with representatives from all garden sectors, meets regularly to update and share disaster recovery plans, specialist resource requirements and emergency contact details.

4. Disaster management planning

4.1 Policy and legal frameworks for disaster management

A critical foundation and instrument for the international community and governments to devise disaster management planning are the policy and legal frameworks under which disaster risk reduction operates. At the international level, there are number of covenants aiming to regulate and guide disaster management that also have a bearing at the institutional level on botanic gardens (Box 5A-D).



BOX 5A: The Sendai Framework for Disaster Risk Reduction 2015-2030 (Sendai Framework) is the first major agreement of the post-2015 development agenda and provides Member States with concrete actions to protect development gains from the risk of disaster. The Sendai Framework works hand in hand with the other 2030 Agenda agreements, including The Paris Agreement on Climate Change, The Addis Ababa Action Agenda on Financing for Development, the New Urban Agenda, and ultimately the Sustainable Development Goals.

It was endorsed by the UN General Assembly following the 2015 Third UN World Conference on Disaster Risk Reduction (WCDRR), and advocates for: *The substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries.*

The Sendai Framework applies to the risk of small-scale and large-scale, frequent and infrequent, sudden and slow-onset disasters, caused by natural or man-made hazards as well as related environmental, technological and biological hazards and risks. It aims to guide the multi-hazard management of disaster risk in development at all levels as well as within and across all sectors It recognizes that the State has the primary role to reduce disaster risk but that responsibility should be shared with other stakeholders including local government, the private sector and other stakeholders.

The following priority actions are included in the Sendai Framework:

- Understanding disaster risk;
- Strengthening disaster risk governance to manage disaster risk;
- Investing in disaster risk reduction for resilience;
- Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction.

BOX 5A-D: MAJOR INTERNATIONAL DISASTER MANAGEMENT POLICY FRAMEWORKS

BOX 5B: The Paris Agreement is a legally binding international treaty on climate change. It was adopted by 196 Parties at the Conference of the Parties (COP) 21 to the United Nations Convention on Climate Change (UNFCCC) in Paris and entered into force on 4 November 2016. Its goal is to limit global warming to well below 2, preferably to 1.5 degrees Celsius, compared to pre-industrial levels. To achieve this long-term temperature goal, countries aim to reach a global peak of greenhouse gas emissions as soon as possible to achieve a climate neutral world by mid-century. The Paris Agreement is a landmark in the multilateral climate change process because, for the first time, a binding agreement brings all nations into a common cause to undertake ambitious efforts to combat climate change and adapt to its effects. Amongst others, key aspects of the Paris Agreement include:

Adaptation (Art. 7) – The Paris Agreement establishes a global goal on adaptation – of enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change in the context of the temperature goal of the Agreement. It aims to significantly strengthen national adaptation efforts, including through support and international cooperation. It recognizes that adaptation is a global challenge faced by all. All Parties should engage in adaptation, including by formulating and implementing National Adaptation Plans, and should submit and periodically update an adaptation communication describing their priorities, needs, plans and actions. The adaptation efforts of developing countries should be recognized.

Loss and damage (Art. 8) – The Paris Agreement recognizes the importance of averting, minimizing and addressing loss and damage associated with the adverse effects of climate change, including extreme weather events and slow onset events, and the role of sustainable development in reducing the risk of loss and damage. Parties are to enhance understanding, action and support, including through the Warsaw International Mechanism, on a cooperative and facilitative basis with respect to loss and damage associated with the adverse effects of climate change.

BOX 5C: The 2030 Agenda for Sustainable Development is a global plan of action for people, planet and prosperity. It also seeks to strengthen universal peace and larger freedom. This Agenda includes a number of objectives related to the management of natural and man-made disasters such as:

1.5 By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters.

2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.

11.5 By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations.

11.b By 2030, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels.

13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries.

BOX 5D: The New Urban Agenda is the 20-year global blueprint adopted by the United Nations Conference on Housing and Sustainable Urban Development or Habitat III in Quito, Ecuador, in October 2016. Among other components, it calls for exploring and developing feasible solutions for climate and disaster risks in cities and human settlements.

Against the backdrop of a world where conflicts, natural disasters and disease are driving ever greater numbers of people to seek remedies for their hunger, safety and survival, the Grand Bargain is a unique agreement between some of the largest donors and humanitarian organisations who have committed to get more means into the hands of people in need and to improve the effectiveness and efficiency of the humanitarian action. The Grand Bargain is about harnessing the vast experience and expertise from across the humanitarian community and bringing it into a realignment which is better prepared for tackling the emergency needs of more than 125 million people, fully recognising the diverse needs defined by their age, gender and abilities.

Growing a new generation of environmental custodians, Reserva Científica Ébano Verde, Dominican Republic. (Joachim Gratzfeld)

Legal frameworks for disaster risk reduction should include institutional mandates, allocate dedicated resources, facilitate the participation of communities, civil society and vulnerable groups, and establish the responsibility and accountability of relevant actors. Effective frameworks facilitate the mainstreaming of disaster risk reduction into relevant sectors, are sustainable within the available resources and capacity of government at national and local levels, and fit within the overall legal and institutional structure of the country (IFRC and UNDP 2014; Bello *et al.* 2021). From a total of 43 countries, 43.8% of the survey respondents indicated that there was no national, legal provision as to the need for an institutional disaster management strategy or policy, whereas 38.2% gave an affirmative answer (Figure 8). Whilst it is encouraging that a number of countries do have related legal frameworks, the results do not allow to gauge their effectiveness or levels of implementation.

In a similar vein, 40.4% of the BGCI survey respondents indicated that their institution had a disaster management strategy or policy, and 43.8% said that their institutions had no strategy or policy (Figure 9). Common topics included in botanic garden disaster management plans are risk assessments (72.5 %), communication plans (55%), staff training in disaster management (52.5%), first aid equipment (50%) and collection-specific disaster management plans (50%) (Figure 10). Less common are duplication of threatened or rare plants at other botanic gardens (37.5%), and selection of plant species better adapted to extreme weather conditions (32.5%). Some institutions have management plans in place for specific areas of the garden to respond to immediately life-threatening and destructive hazards such as fires, but not for overall extreme climate events such as drought (for example wild areas in Cadereyta Regional Botanical Garden, Mexico).

FIGURE 8: INSTITUTIONAL DISASTER MANAGEMENT STRATEGY OR POLICY REQUIRED BY NATIONAL LAW (N=89; 43 COUNTRIES)

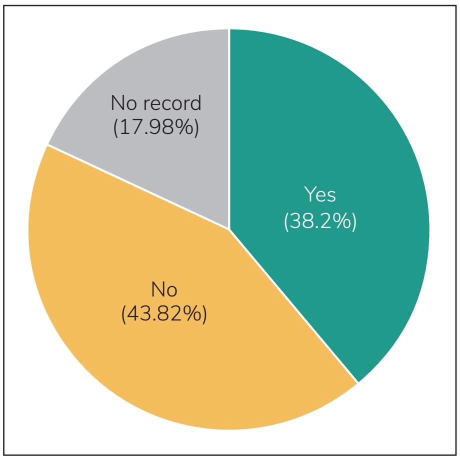


FIGURE 9: INSTITUTIONS WITH OR WITHOUT A DISASTER MANAGEMENT STRATEGY OR POLICY (N=89; 43 COUNTRIES)

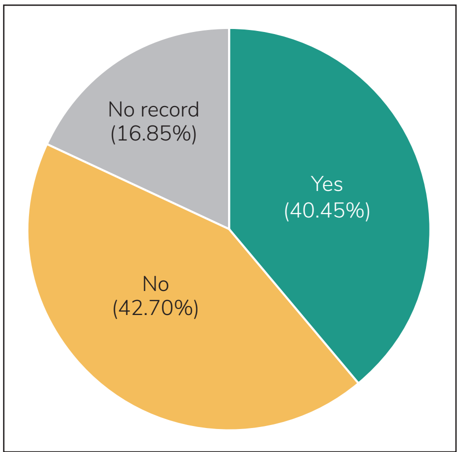
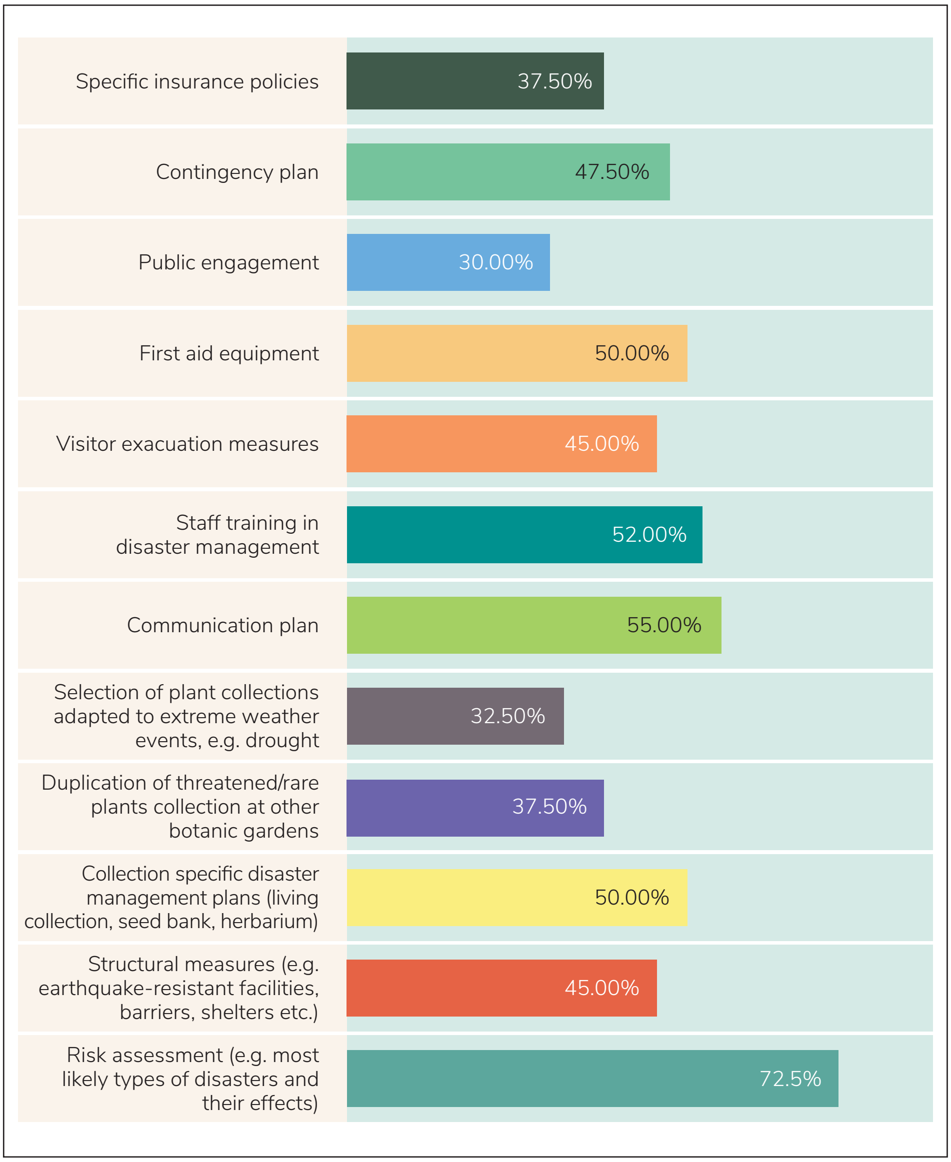


FIGURE 10: COMMON TOPICS INCLUDED IN INSTITUTIONAL DISASTER MANAGEMENT STRATEGIES (N=40)



CASE STUDY: Emergency response plan at Beijing Botanical Garden, China

Xu Xing and Jiao Mingzhang

Beijing Botanical Garden lies in the foothills of West Hill, Beijing, China. The climate is temperate, with a semi-humid, monsoonal season. The average annual temperature, precipitation and sunshine length is 11-12 ˚C, 640 mm and 2,000-2,800 hours, respectively.

Beijing Botanical Garden was founded in 1956. During the winter of 2008, the Garden was hit by freezing rain causing damage to and loss of plant collections and decrease of income. As that year had experienced a climate anomaly, leaves of many specimens had not completely fallen. The sudden appearance of freezing rain caused major damage to branches and the plants. This event contributed to greater alertness of staff to changes in the climate and closer study of meteorological data to be better prepared in the event of extreme weather incidents. It also focused attention to the importance of regular horticultural maintenance work, including tree pruning and thinning, carried out year-round.

The Garden has developed an extreme weather and emergency response plan targeting high winds, heavy rain, snow, hail, lightning, and mixed extreme weather events (two or more extreme weather warnings). Based on the level of harm that may be caused by such disasters, the degree of urgency is divided into four levels: IV (general), III (more serious), II (serious), I (especially serious). The Garden's Security Department is responsible for tracking the forecast by the meteorological department and releasing early warning information as well as lifting of the warning. Depending on the type and magnitude of the disaster, every department of the Garden has particular responsibilities. For example, the Management Department is in charge of setting up extreme weather warning signs at each gate to remind visitors to pay attention to safety. The Security Department and Park Protection Department are responsible for monitoring and inspecting the susceptible areas, including infrastructures, roads, bridges, water, safety and recreational facilities, hill sites, etc., whilst the Horticulture Department takes care of tree inspection and management. The emergency response plan is regularly updated.

Emergency response plan of Beijing Botanical Garden


Beijing Botanical Garden. (Wang Xin)

CASE STUDY: **Disaster management at the Muséum national d'Histoire naturelle (MNHN), Paris**
Jacques Cuisin and Denis Larpin

The historic site of the National Museum of Natural History (MNHN) located at the Jardin des Plantes in Paris, France, benefits from a fairly temperate climate. Created in 1626 by King Louis XIII as a medicinal plants garden, over time it evolved into a museum dedicated to the study of natural history and was officially named MNHN in 1793. Since then, the institution continued to grow as regards the collections, buildings and locations, extending to 13 sites. Throughout this long history, conservation planning for the collections in the event of a disaster was limited, and even today, the notion of an emergency management plan does not yet exist.

The emergence of 'preventive conservation' in the 1980s coincided with the creation of the Zoothèque. However, even though this building was elaborated and built for the conservation of a large number of animal specimens (around seven million today, representing 10% of the MNHN collections), little has been thought of in the event of a major disaster. Likewise, recent building renovations did not include an emergency management plan, neither for the Grand Herbier/Herbarium (2012), the Musée de l'Homme (2009-2015), nor for the Paleontology collections (2019-2021). There are several reasons for this, but first and foremost this is due to the very fragmented organisation of the collections between 1793 and 2008 with each specialty (botany, zoology, etc.) managing its own collections. Since 2008, a unique Collections Department acts for all collections, but it does not yet include a dedicated conservation planning service.

Another element is proving both favourable and unfavourable to emergency management: the number of buildings. The plan drawn in 1806 shows barely half of the current buildings, and most of these old constructions are of modest size. The location of buildings in different sites means that fire, for example, cannot destroy the totality of the collections, unlike at the National Museum of Natural History in Lisbon in 1978, or at the National Museum of Brazil in 2018. Another favourable factor is the organisation of the collections: type specimens are often separated from the rest of the collection.

If the antique nature of numerous buildings gives rise to fears of fire, the MNHN especially is concerned by the risk of flooding from the nearby Seine. The river overflowed very significantly in 1910, but it is not known how many of the collections were affected due to the lack of a precise inventory at that time. In 2016 and 2018, significant fluctuations in the level of the Seine required a rapid moving of certain paleontological collections, yet without any real concerted plan tested in advance. Whilst other alerts have always been managed *ad hoc*, damage to the collections comprising over 68 million specimens fortunately has remained relatively minimal with some hundred reference collections lost over the past 30 years.

Since the creation of the centralized Collections Department, a comprehensive vulnerability study was carried out in 2013. This serves as strong basis to elaborate and test a part of the emergency plan (moving the collections before a potential flood), especially in the Comparative Anatomy collection building. With many of the botanical collections stored in several buildings, these tests and experiences will be of great importance in developing a comprehensive emergency management plan.

Inundations caused by the river Seine at the Jardin des Plantes, Paris, in 1910. (Bibliothèque centrale, Muséum national d'Histoire naturelle, Paris)

Water damage, occurred in 2015, to Georges Cuvier's anatomical boxes, which are dated around 1825-1830. (Jacques Cuisin)

4.2 General components of disaster management planning for botanic gardens

As botanic gardens vary widely in geography, collections, operations and potential threats they are exposed to, the development and periodic review of a tailor-made disaster management plan is essential. Though the topic may be uncomfortable, it can also bring peace of mind and inspire purposeful action in the face of potential chaos (APGA 2016). Whilst the plant collections may be at the centre of concern in disaster planning for botanic gardens, business continuity is equally critical to ensure that vital infrastructure such as irrigation systems, electricity, information technology, etc. are maintained or can be restored rapidly if they have been affected by a disaster.

To provide a general outline of a disaster management plan for botanic gardens that can be adapted to the particular local situation, the main planning stages should be considered. A comprehensive and integrated example of the disaster management cycle is provided by the National Disaster Management Authority, Indonesia (Figure 11), with the government and local authorities responsible for disaster management operations (BNPB 2019; 2014). The main disaster management stages comprise:

FIGURE 11: DISASTER MANAGEMENT CYCLE OF THE NATIONAL DISASTER MANAGEMENT AUTHORITY IN INDONESIA (BNPB 2019)

Prevention and mitigation – no disaster situation

Preparedness – pre-disaster situation or potential disaster approaching

These two stages comprise all actions that aim to strengthen the capacities and resilience of government and communities to protect lives, livelihoods, infrastructure and resources (e.g. the collections) through measures to avoid (prevention) or limit (mitigation) the negative impact of potential hazards and to provide timely and reliable hazard forecasts, including the likely centre and distribution, magnitude and impact of a disaster. This is facilitated by a comprehensive disaster risk assessment that looks at impact versus probability of a hazard to categorize and prioritize risks as some risks may have a severe impact but only happen on rare occasions, while other have a moderate impact but occur more frequently. The disaster risk assessment will inform the nature and magnitude of the management response that will be required (Table 1).

Emergency response – action in the acute phase of disaster

Following the occurrence of a disaster, immediate and effective actions are necessary to save lives, protect health, stabilize conditions and further deterioration of resources. During this stage, there are typically two further types of assessment needed: an initial rapid appraisal determining the nature and magnitude of the emergency, as well as the possible need for external assistance, and secondly, a detailed sector assessment to plan, implement and coordinate the response. This rapid appraisal should provide data on the number of people, infrastructure and resources affected to identify immediate needs.

Recovery – post-disaster rehabilitation

Initially this phase seeks to accelerate the early recovery of livelihoods and socio-economic activities in the affected area. This includes detailed data collection on the number of people, infrastructure and resources affected, the estimated economic loss and the needs that are required for recovery. Practical action involves the rehabilitation and reconstruction of infrastructure and resources, such as water supply and sanitation facilities, and the collections. The focus is to return the social and economic life and day-to-day operations to its normal state as quickly and efficiently as possible, although temporary arrangements may have to be made.

Whilst this presents a general disaster management cycle, in reality, the shift between these phases is flowing and not clear-cut. For instance, rehabilitation and new development efforts also integrate aspects of future disaster risk reduction and hazard mitigation strategies.

Right: Flood damage to pathways at the Harold Porter National Botanical Garden, South Africa, following the 2005 floods. (Christopher Willis)

TABLE 1: DISASTER RISK ASSESSMENT MATRIX

Likelihood level of a disaster	Consequence (impact) level of a disaster				
	1 Negligible	2 Minor	3 Moderate	4 Major	5 Severe
1 Remote	1	2	3	4	5
2 Unlikely	2	4	6	8	10
3 Possible	3	6	9	12	15
4 Likely	4	8	12	16	20
5 Certain	5	10	15	20	25

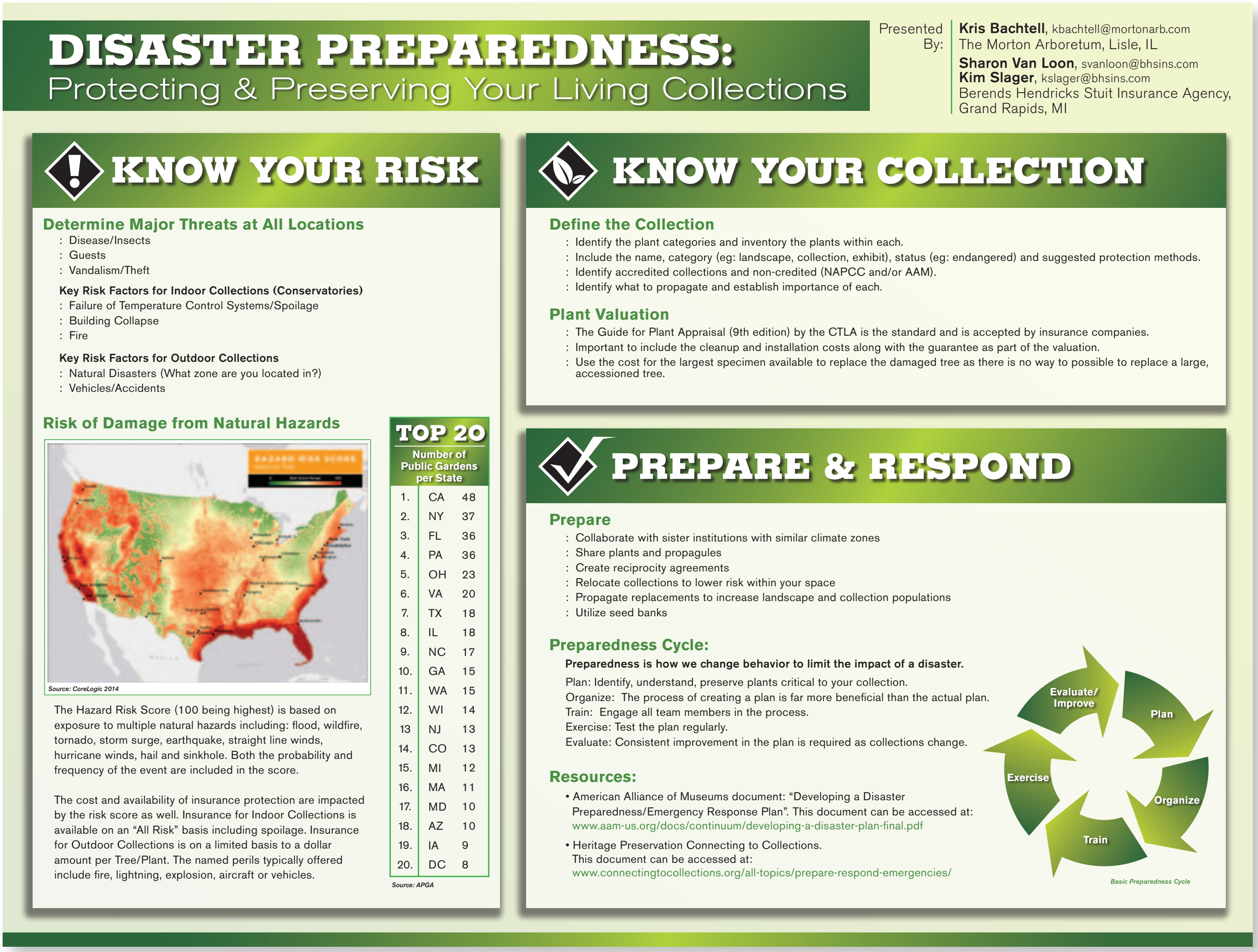
Risk level	Risk score	Management response
Low	1 - 3	No specific management will be required
Medium	4 - 6	Specific management will be required
High	8 - 12	Enhanced management will be required
Extreme	15 - 25	Extensive management will be required

The disaster risk assessment matrix involves the calculation of the magnitude of potential disaster consequences (impacts) and the likelihood (probability) of these consequences to occur (risk = consequence (C) x likelihood (L)). The C × L matrix combines the scores from the qualitative or semi-quantitative ratings of consequence and likelihood that a specific consequence will occur to generate a risk score and risk rating. The higher the likelihood of a worse effect occurring, the greater the level of risk. The C x L risk assessment process involves selecting the most appropriate combination of consequence and likelihood levels that fit a particular situation, e.g. for a collection, based on the information available and the knowledge of the concerned group who assesses the risk. For instance, if it is concluded that the most appropriate combination for the assessment of the risk posed by a particular hazard to the collection is that it is likely that a severe consequence could occur, the related two scores are multiplied (4 x 5) generating a very high, extreme risk (20). Therefore extensive management actions would be needed to secure the collection. The specific actions that will be required need to be aligned with the nature of the disaster and its impact on the individual garden components, such as living collections and infrastructure. The colour scheme highlights the different risk scores and the risk categories (low risk in green; medium risk in light amber; high risk in orange and extreme risk in red).

As with museums and other cultural institutions managing collections which have a particular track record in disaster management planning (e.g. Collections Trust; The Getty Conservation Institute; American Alliance of Museums; American Institute for Conservation/Foundation for Advancement in Conservation), many botanic gardens maintain disaster management plans based on the above main management stages. Disaster management planning increasingly is also a requirement by government agencies, insurance companies and accreditation programmes (APGA 2016). For example, some networks such as the American Public Gardens Association require preparedness planning as a criterion for their Plant Collections Network accreditation (Figure 12).

Collections assessment after Hurricane Irma. (Montgomery Botanical Center)

FIGURE 12: POSTER BY KRIS BACHTELL PRESENTED AT THE AMERICAN PUBLIC GARDENS ASSOCIATION'S PLANT COLLECTION SYMPOSIUM, WASHINGTON, DC, IN 2014.



CASE STUDY: Hurricane Katrina and Hurricane Wilma shaped our response and knowledge, Montgomery Botanical Center, Florida, USA

M. Patrick Griffith

Montgomery Botanical Center is a botanic garden specializing in palms and cycads located at sea level in Miami, Florida, United States of America, in a subtropical climate that is becoming more and more tropical. Montgomery started as a plant collection in 1932, and as a not-for-profit botanical institution in 1959.

In 2005, Montgomery was hit by Hurricane Katrina and Hurricane Wilma, almost exactly two months apart. Thankfully no one was injured in the storm, and careful emphasis placed on safety during the recovery period ensured no one was hurt removing debris. Although some facility damage occurred, the major losses were in the plant collections. The cost of debris removal was estimated around USD (US dollar) 100,000, but this did not account for all labor mobilized in this effort.

We were glad to receive financial reimbursement for our recovery effort from the US Federal Emergency Management Agency. But 'debris,' as termed by the government response authorities, comprised our beloved collections, thereby highlighting an important misunderstanding about downed trees post-hurricane. We worked to carefully assess damage before removing plant material, while the authorities rewarded swift removal effort. We did implement our standing disaster response protocol after Hurricane Katrina, but our recovery experience led us to refine that protocol prior to Hurricane Wilma – we sought to increase the flexibility of our response to account for larger scale disasters.

Our main lesson in all of this was to "*be prepared, but be flexible*" – our rigid, detailed protocol pre-Katrina was well thought out, but could not account for balancing thorough assessment with large scale recovery actions. We built flexibility into our new plan just before Hurricane Wilma, with great results; we were able to complete a quick collections triage, followed by parallel assessment and recovery efforts. This experience was again called upon in 2017 for Hurricane Irma, and informed our response well – even though Irma was much more serious (USD 500,000 in damage) than both of our 2005 storms combined. In addition, Post-hoc study of the collections assessment demonstrated the value of choosing locally-adapted species, and especially highlighted the differences between Caribbean palms and South American palms – showing how disasters can provide opportunities for scientific and botanical advancement.

Uprooted Cananga odorata (Annonaceae) at Montgomery Botanical Center. (Montgomery Botanical Center)

Re-erecting the uprooted Corypha taliera at Montgomery Botanical Center. (M. Patrick Griffith)

Whilst disaster management plans vary greatly in the level of detail and sophistication of procedures – for instance depending on the size of the institutions and the uniqueness of their collections – every botanic garden should consider disaster management planning as an integral part of its institutional policy framework such as in the example of Montgomery Botanical Center, Florida provided in Figure 13, and engage members of staff in the development process (Table 2).

Figure 13: Increased hurricane activity predicted for future decades has serious implications for the Montgomery Botanical Center, Florida. The recovery process begins immediately following each hurricane, but preparedness is just as important to weathering the storm for the Montgomery Botanical Center.

TABLE 2: GENERAL TEMPLATE AND CHECKLIST FOR DISASTER MANAGEMENT PLANNING.

BEFORE	PREVENTION					
	• Risk assessment – on staff, collections, infrastructure and operations, visitors					
	Disaster type	Likelihood level	Consequence level	Risk rating (C x L)	Management response	Members of staff responsible*
	Drought					
	Flood					
	Etc					
	• Disaster adapted infrastructure and collections – spatial planning based on potential risk, hazard-proof construction, climate and climate change-adapted plant collections, business logistics such as communications, internet, water and energy systems					
	• Securing collections in the long-term – maintenance best-practice, duplication of collections at other institutions					
	• Forecasting and monitoring disasters – early warning systems, collaboration with other institutions in similar climate or seismic zones					
	• Up-to-date inventories of infrastructure and equipment					
	PREPAREDNESS					
	• Capacity building needs – prevention, mitigation, first aid, collections protection and rescue, tree management					
	• Integration of disaster management in the institutional strategic frameworks such as the collections policy					
	• Links to national, regional and international disaster management plans, legislative frameworks and policies					
	• Coordinated emergency communications system					
	• Evacuation signage and awareness materials for staff and visitors					
	• Technical and financial support structure in place – government, local community, private, corporate, international					
	• Regular risk assessment update and testing of the disaster response procedures					
	• Invite third parties to help identify areas of improvement such as local emergency response providers, companies specialised in disaster recovery, insurance brokers					
DURING	RESPONSE					
	• Rapid assessment – disaster impact magnitude and needs, health of staff/visitors, conditions of collections and infrastructure					
	• Emergency action – evacuation, first aid, psychological support, shelter for staff/visitors, rescue of damaged collections, securing of broken infrastructure and equipment, removal of major debris					
AFTER	RECOVERY					
	• Detailed assessment of impact, and technical and financial needs – staff, visitor, infrastructure, collections, cost estimates					
	• Removal of debris					
	• Reconstruction – infrastructure, irrigation, drainage, collections					
	• New accessioning for collections					
	• Solidarity – national, regional and international botanic garden network support					
	• Public outreach and fundraising – dissemination of information on recovery progress and further needs					

**Members of staff responsible will vary depending on the size of the botanic garden, personnel set-up (e.g. Health & Safety, emergency response team, etc.), collection and programme focus, etc.*

5. Conclusions

Disasters – natural and/or man-made – and their consequences are on the rise. While improved recording and reporting may explain some of these increases, there is more evidence than ever that in a world where the global average temperature in 2019 was 1.1˚C above the pre-industrial period, there is increased frequency of extreme weather events such as heatwaves, droughts, wildfires, flooding and storms (WMO 2019). In addition, the overlap of disasters and the interplay between risk drivers such as poverty, climate change, air pollution, population growth (especially in hazard-prone areas), uncontrolled urbanization and loss of biodiversity, require enhanced and better, globally coordinated disaster risk governance and management (UNDRR 2020).

As exceptionally multifaceted institutions managing diverse plant collections and a wealth of conservation, research and public engagement programmes including associated facilities and equipment, botanic gardens are confronted with a multitude of effects and challenges when struck by disaster. It almost goes without saying that the first and foremost priorities are the health and safety of staff, but next in importance is the gardens' natural capital - their living collections and other botanical holdings that are at the centre of any botanic garden.

This Review has shown the commitment and perseverance of botanic gardens to save and secure the natural heritage in their collections and garden grounds, but also the frustration and despondency, when aged or very rare specimens let alone entire plant holdings are lost forever in a disaster. This innate sense of responsibility has also spurred many botanic gardens to develop risk management strategies and plans to be better prepared in the event of disaster, to mitigate the impacts and recover more quickly. The COVID-19 pandemic in particular, in spite of its devastating global effects, has demonstrated the resilience and great potential for innovation that botanic gardens are capable of mobilising within a short time to ensure the maintenance of their collections and facilities and to remain engaged with the public.

Haemanthus canaliculatus (Amaryllidaceae) flowering after the March 2015 summer fires in the coastal wetlands of the Harold Porter National Botanical Garden, South Africa. (Christopher Willis)

However, even though there are inspiring examples of how gardens have been tackling and recovering from disaster, these cases are far from being universal and major efforts are required to support less affluent organisations to build on best-practice and replicate disaster risk planning in their specific, local contexts. As highlighted in this report, there are a number of technical guidance and policy frameworks on hand such as the Sendai Framework that help structure the development and implement disaster management strategies and action plans. These are also applicable to the global botanic garden community and are based on the principles of:

- Understanding disaster risk in all its dimensions, such as disaster type, characteristics and impacts, including vulnerability of staff and collections but also their capacity to weather hazards;
- Enhancing disaster management planning for effective prevention, mitigation, preparedness and response, which are incorporated in a comprehensive risk management plan based on the specific, local circumstances as outlined in Table 2 above;
- Securing financial and technical assistance from local, national and international sponsors and supporters to invest in risk reducing, structural and non-structural measures, as well as draw on aid in the event of disaster; and
- Strengthening botanic garden networking at the national, regional and global levels to foster collaboration and partnership, and active participation in international strategies and policies for better disaster risk governance and reduction.

Building technical capacity to manage and reduce the impact of future disasters is a principle that cuts across all stages of disaster management planning. This Technical Review carried out by BGCI based on experiences and data made available by numerous botanic gardens, supports this endeavour in an area of rapidly growing importance, yet with still very few resources specific to botanic gardens. BGCI is committed to supporting the global botanic garden community, through the mobilisation of technical expertise and financial assistance, to help ensure that botanic gardens continue to conserve biodiversity and promote human wellbeing at a time when disasters are increasing dramatically in frequency and potency.

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Annex 1 Contributing institutions

Botanical Garden of the Institute of Botany a. A. Takhtajyan, National Academy of Sciences	Armenia
Tasmanian Arboretum	Australia
Royal Botanic Gardens and Domain Trust	Australia
Royal Botanic Garden Sydney	Australia
Blue Mountains Botanic Garden Mount Tomah	Australia
Royal Botanic Gardens Victoria	Australia
Institute of Dendrology Azerbaijan National Academy of Sciences	Azerbaijan
Bangladesh Agricultural University Botanical Garden	Bangladesh
Andromeda Botanic Gardens	Barbados
Bermuda Botanical Gardens - Department of Parks	Bermuda
Jardín Botánico La Paz - Instituto de Ecología, Universidad Mayor de San Andrés	Bolivia
Jardim Botanico Araribá	Brazil
Joseph Reynold O'Neal Botanic Gardens	British Virgin Islands
Royal Botanical Gardens	Canada
Huella Natureza	Chile
Beijing Botanical Garden	China
Shanghai Chenshan Botanical Garden	China
Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences	China
Gannan Arboretum	China
Minqin Desert Botanic Garden	China
Jinchang Botanical Garden	China
Shanghai Botanical Garden	China
South China Botanical Garden, Chinese Academy of Sciences	China
Taipei Botanic Garden, Taiwan Forestry Research Institute	Taiwan, China
Botanical Garden of National Museum of Natural Science	Taiwan, China
Jardín Botánico de Bogotá Jose Celestino Mutis	Colombia
Jardín Botánico de Popayán	Colombia
Jardín Botánico de Cartagena “Guillermo Piñeres”	Colombia
Prague Botanical Garden	Czech Republic
Yachay Botanical Garden	Ecuador
Jardin des Plantes - Muséum national d'Histoire naturelle	France
Jardin botanique de Talence	France
Batumi Botanical Garden	Georgia
Botanical Garden of the University of Potsdam	Germany
Palmengarten Frankfurt am Main	Germany
Botanical Garden of Ulm University	Germany
Jardin botanique des Cayes	Haiti
Eötvös Loránd University Botanical Garden	Hungary
University of Pécs Botanic Garden	Hungary
Folly Arborétum és Borászat	Hungary
Auroville Botanical Gardens	India
Jawaharlal Nehru Tropical Botanic Garden and Research Institute	India
Kurdistan Botanical Foundation	Iraq
Royal Botanic Garden	Jordan
National Botanic Garden	Latvia
Vytautas Magnus University Botanical Garden	Lithuania
Botanical Garden of Vilnius University	Lithuania
Kepong Botanic Garden, Forest Research Institute Malaysia	Malaysia
Rainforest Discovery Centre, Sabah Forestry Department	Malaysia
Argotti Botanic Gardens & Resource Centre	Malta

Cadereyta Regional Botanical Garden	Mexico
Jardín Etnobiológico de las Selvas del Soconusco	Mexico
Auckland Botanic Gardens	New Zealand
Wellington Botanic Garden ki Paekākā	New Zealand
Ōtari Native Botanic Garden and Wilton's Bush Reserve	New Zealand
University Gardens, University of Bergen	Norway
Qarshi Botanical Garden	Pakistan
Katala Foundation	Philippines
Makiling Botanic Gardens	Philippines
Siit Arboretum Botanical Garden Inc.	Philippines
Botanical Garden of Ajuda	Portugal
Botanical Garden of Tver State University	Russian Federation
Institute of Botany and Botanical Garden "Jevremoac"	Serbia
Harold Porter National Botanical Garden	South Africa
Real Jardín Botánico	Spain
University of Alcalá Botanic Gardens	Spain
Gothenburg Botanical Garden	Sweden
Botanical Garden, Lund University	Sweden
Linnaean Gardens of Uppsala	Sweden
Jardin botanique de la Ville de Neuchâtel	Switzerland
Public institution "Donetsk Botanical Garden"	Ukraine
Royal Botanic Gardens Kew	United Kingdom
Royal Botanic Garden Edinburgh	United Kingdom
Chicago Botanic Garden	United States of America
Oklahoma City Zoo & Botanical Garden	United States of America
Botanic Garden of Smith College	United States of America
Mount Holyoke College Botanic Garden	United States of America
Naples Botanical Garden	United States of America
Bok Tower Gardens	United States of America
Montgomery Botanical Center	United States of America
Conservatory of Flowers	United States of America
U.S. National Arboretum	United States of America
Marie Selby Botanical Gardens	United States of America
Bernheim Arboretum and Research Forest	United States of America
Filoli	United States of America
Houston Botanic Garden	United States of America
Red Butte Garden	United States of America
Alaska Botanical Garden	United States of America
Phu An Bamboo Ecomuseum and Botanic Gardens	Viet Nam
Bidoup Nui Ba Botanic Garden	Viet Nam
National Botanic Garden	Zimbabwe

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Kepong Botanic Garden, Malaysia, with *Ruellia simplex* in the foreground. (Suhaida Binti Mustafa)

Andromeda Botanic Gardens, Barbados. (Sharon Cooke)

BOTANIC GARDENS CONSERVATION INTERNATIONAL