

# The Climate Change Alliance: botanic garden horticulturists as agents for change

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## Abstract

In 2016, the publication of the pioneering Landscape Succession Strategy heralded a horticultural response by Royal Botanic Gardens Victoria to climate change risks faced by their living collections. This initiative led to the botanical world's first Climate Change Summit in 2018 and the subsequent establishment of the Climate Change Alliance of Botanic Gardens. This article describes some of the anticipated climatic changes facing the Melbourne Gardens site, the strategic management of collections when considering these challenges, and how other botanical organisations can benefit from this approach through collaboration and sharing of expertise.

## Melbourne Gardens, Royal Botanic Gardens Victoria

Royal Botanic Gardens Victoria (RBGV) was established in 1846 on the banks of the Yarra River in Melbourne, Victoria (Australia). Today, the organisation encompasses two diverse sites: the original Gardens in Melbourne and the Cranbourne Gardens, first established as a division of RBGV in 1970 and open to the public since 1989. Melbourne Gardens are also home to the State Botanical Collection, held at the National Herbarium of Victoria, comprising the largest herbarium collection in Oceania (Thiers, 2021). RBGV is managed by the Royal Botanic Gardens Board Victoria, which is responsible to the Minister for Environment and Climate Change.

The Melbourne Gardens site covers 38.6 ha and is located about 2.4 km from the centre of the city of Melbourne. Melbourne Gardens can be portrayed as a 'Garden of the World', with the most recent analysis (RBGV,

2021b) confirming that 189 countries (98 per cent of recognised sovereign states) are represented in its living collection of over 7,500 taxa. The high plant diversity of the collections and landscape at Melbourne Gardens provides significant benefits to human wellbeing (Fuller *et al.*, 2007; Shanahan *et al.*, 2015) and, in common with many other botanic gardens, enables abundant learning and storytelling for visitors (Westwood *et al.*, 2021).

Acknowledging that all accessioned specimens contribute to the Melbourne Gardens' living collection, there are over twenty actively curated collections grouped under five themes: Geographical; Ecological; Taxonomic and Evolutionary; Research and Conservation; and Ornamental and Cultural (Fig. 1). Each collection is overseen by a curator who develops and maintains these collections according to a Living Collections Strategy and collection-specific management plans.

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**Fig. 1** Guilfoyle's Volcano (Ornamental and Cultural collection), as captured by drone during the 175th anniversary celebrations held for Melbourne Gardens. The Arid Garden, which can be seen towards the top left, forms part of the Cacti and Succulent (Taxonomic and Evolutionary) collection. Photo: A. Vittorio.

## Risks to the living collections at Melbourne Gardens

### *Climatic change: past*

Melbourne's historic mean annual temperature from 1856 to 1950 was 14.7 °C. However, the mean annual temperature in the last 30 years has been about 16.2 °C (Australian Bureau of Meteorology, 2021b). Actual temperature change attributed to global warming since 1910 is about 1 °C (Grose *et al.*, 2015; Clarke *et al.*, 2019). Some of this additional temperature rise could also be due to the growth of the city of Melbourne, resulting in increased urban thermal mass and urban heat island (UHI) effects (Akbari *et al.*, 2016). Mean annual precipitation for Melbourne has sat at about 645 mm for most recorded years, but for the last 30 years that figure has fallen to an average of 592 mm and appears to be on a downward trend

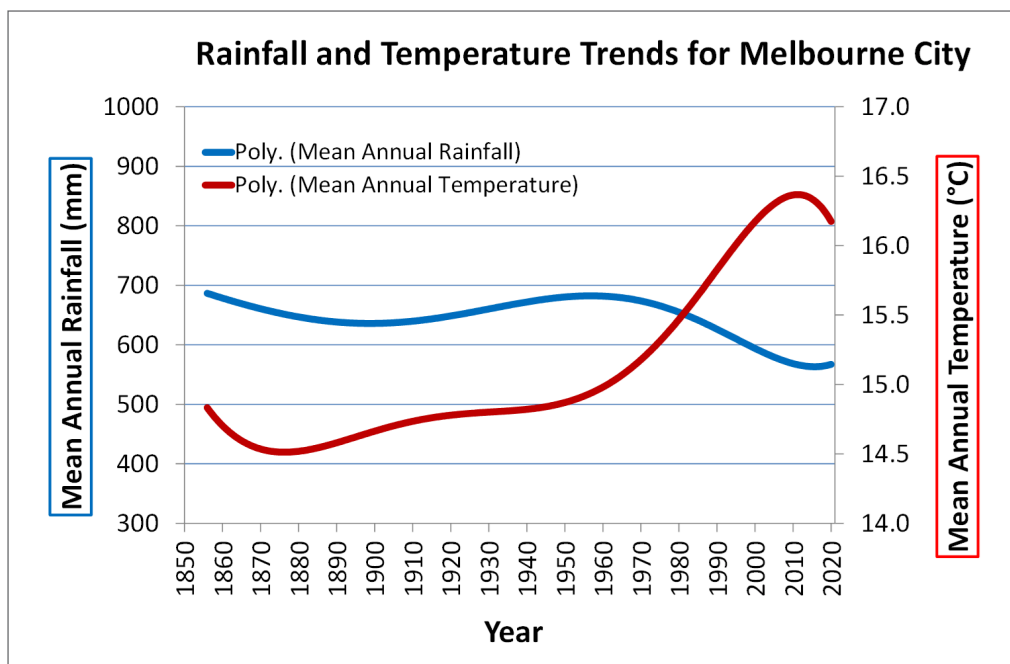
(Australian Bureau of Meteorology, 2021b).

In effect, the 'climatic envelope' (Fig. 2) in which Melbourne Gardens were established is already history and substantial change is projected to continue.

### *Climatic change: future*

Under the current climate change scenarios of RCP4.5 and RCP8.5,<sup>3</sup> by 2090 Melbourne could see the mean annual temperature rise by median values of 1.95 °C to 3.45 °C

<sup>3</sup>RCP4.5 and RCP8.5 are Representative Concentration Pathways, from Global Climate Models, representing 'intermediate' and 'business as usual' emissions scenarios respectively. These RCP scenarios were published by the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5). The IPCC is now in its sixth assessment cycle to produce the Sixth Assessment Report (AR6) in 2022. This report is likely to apply new Shared Socioeconomic Pathways (SSPs) scenarios based on the sixth phase of the Coupled Model Intercomparison Project (CMIP6) (Grose *et al.*, 2020).



**Fig. 2** Simplified scatter plot (points removed) of annual temperature and precipitation trends for Melbourne. Data sourced from Australian Bureau of Meteorology (2021b). Note that Melbourne's official weather observation station was relocated in 2015 and that 2020 was substantially wetter than average (Australian Bureau of Meteorology, 2021a). These changes are likely to have momentarily affected the temperature trend. Chart: P Symes.

respectively (Clarke *et al.*, 2019). Based on the 1986–2005 mean annual temperature of 15.9 °C, the realisation of an RCP8.5 scenario may then result in a mean annual temperature of up to 19.3 °C (Clarke *et al.*, 2019). As background mean temperatures increase, extreme temperatures become more likely (CSIRO & BOM, 2020). It is projected that, by that point, Melbourne could have up to twice as many days over 35 °C (from 8.3 to 16 days under RCP8.5) (Clarke *et al.*, 2019) and four times as many days over 40 °C (from 1.6 to 6.8 days under RCP8.5) (Webb & Hennessy, 2015).

Note that projected global temperature rises found in the RCP8.5 scenarios may be unrealistically high (Forster *et al.*, 2020) and are disputed by some authorities, who suggest that rises of 3 °C above pre-industrial levels could be more likely by the turn of the

century (Hausfather & Peters 2020). RBGV approached this risk to the landscape by applying a 'precautionary principle' (Read & O'Riordan, 2017), noting that carbon emissions were already tracking at high-level scenarios (Peters *et al.*, 2013; Schwalm *et al.*, 2020), that additional urban heat had not been factored into the projections (Huang *et al.*, 2019) and that over 500 taxa in the collections that had originated from estimated median annual temperatures higher than 19 °C were growing well (RBGV, 2021b). This indicated that considering plant selection from origins with higher temperatures was more likely to be sustainable when contemplating temperature rise in the multi-decade time frames of landscape management.

Applying the same RCP4.5 and RCP8.5 scenarios, median values of precipitation

are projected to decrease by 8–20 per cent and pan evaporation increase by 18.9–34.4 per cent respectively (Clarke *et al.*, 2019). Even under the RCP4.5 scenario, demand for annual supplementary irrigation could increase by about 27 per cent, rising to over 50 per cent in an RCP8.5 scenario. Significant reductions in precipitation are projected for the cooler seasons of the year; spring is subject to the worst reductions with a drop of 18–30 per cent (Clarke *et al.*, 2019). These seasonal changes may already be trending. Since the 1990s, a decline in rainfall of about 12 per cent has been observed for April–October (autumn to spring) in the south-east of Australia (CSIRO & BOM, 2020). As the cooler periods are typically when lake systems are recharged for the next irrigation season, these changes to rainfall impact the current stormwater harvesting schemes in Melbourne Gardens.

### *Climate change and threats to plant biodiversity*

The IPCC (2014) outlines (high confidence) that biodiversity richness faces significant threats to survival from climate change and, as quoted, 'A large fraction of species faces increased extinction risk due to climate change during and beyond the 21st century, especially as climate change interacts with other stressors.' If global warming can be limited to 1.5 °C compared to pre-industrial levels (only 0.6 °C above current), it is estimated that 8 per cent of plants could lose half of their climatically defined geographic range – this loss doubles to 16 per cent if warming results in a 2 °C increase (IPCC, 2018). Warren *et al.* (2018) suggest that 44 per cent of plants could lose more than half of their climatically defined range for a warming of approximately 3.2 °C above pre-industrial levels. Within Australia, 47 per

cent of the natural vegetation is estimated to be at potential risk from an increase in mean annual temperature of up to 3.3–3.4 °C by 2070 (Gallagher *et al.*, 2019). Cultivated environments such as botanic gardens, parks and gardens are also threatened as many trees appear confined to climatic envelopes and are likely to face additional warming stress from UHI effects (Kendal *et al.*, 2018). Burley *et al.* (2019) report that, in Australia, the climatically suitable habitat will be reduced for 73 per cent of urban trees that were studied, and for 18 per cent of these species there could be a reduction in climatic range of more than 50 per cent.

The ability to track effective plant migration in response to changes in temperature and precipitation is constrained by altitudinal and geographic limits (Costion *et al.*, 2015; Christmas *et al.*, 2016), and many species cannot shift their geographical ranges rapidly enough to respond to rates of climate change (IPCC, 2014; Corlett, 2016; Booth, 2017). For example, in Australia, *Eucalyptus* spp. have been noted as having relatively poor mechanisms for effective dispersal, with estimated migration rates of only 1–2 m each year (Booth, 2017) – well below a theoretical range shift when future temperature rise is considered. This is further confounded with the higher risks of extinction-level events such as wildfires (Harris *et al.*, 2018) and heatwaves (Ruthrof *et al.*, 2018). Estimates of global plant extinction are already significant due to habitat loss, invasive species and other human-mediated activities, and climate change brings yet another threatening process to the fore (Pimm & Raven, 2017). More recent estimates suggest that 39 per cent of the world's plants could be threatened by extinction, however this does not necessarily factor in the future risks from climate change (Nic Lughadha *et al.*, 2020).

### *Elevation and range shift risks for Australian plant biodiversity*

Risks to plant biodiversity in an Australian context can be demonstrated by examining the limits to montane vegetation. At an average elevation of only 330 m, Australia is the lowest continent in the world. The mountains in other continents can be more than twice as high as Mount Kosciuszko (2,228 m), Australia's tallest peak. In fact, less than 1 per cent of Australian land surface area has an elevation greater than 1,000 m (Geoscience Australia, 2021). Numerous authors have reported on elevation range shifts in montane vegetation – either upwards, presumably in relation to temperature increases (Harsch *et al.*, 2009; Lenoir *et al.*, 2010; Dirnböck *et al.*, 2011), or downslope in response to shifts in vegetation

competition and water availability (Crimmins *et al.*, 2011; O'Sullivan *et al.*, 2021), but the causal components appear to be more complex and go beyond climatic drivers alone (Naccarella *et al.*, 2020; O'Sullivan *et al.*, 2021). *Eucalyptus pauciflora* (snow gum) (Fig. 3) is an iconic Australian species that typically grows at elevations from 700 m (Atlas of Living Australia, 2021) to the alpine treeline at about 1,750–1,900 m (Naccarella *et al.*, 2020). There is evidence that some upslope migration is occurring as temperatures warm (Brookhouse & Bi, 2009; Naccarella *et al.*, 2020), but perhaps in contrast to other areas of the world, Australia's alpine regions are also prone to bushfires that complicate the current understanding of vegetation dynamics (Camac *et al.*, 2017). Hoffmann *et al.* (2019) report on studies conducted on Mount



**Fig. 3** Typical gnarly forms of *Eucalyptus pauciflora* (snow gum) off King Billy Track, near Mount Howitt, Victoria. Photo: P. Symes.

Bogong in the Victorian high country that indicate the combination of more frequent burning (mediated by climate change) and subsequent dominance of shrubby life forms could displace snow gums, as well as alpine grasses and forbs. There are conceivably many areas where snow gums and other species could be constrained by lower peaks and have limited flexibility to redistribute to optimum ecological niches in response to these environmental and competitive pressures (Hughes, 2011).

### *Bushfire risks*

The warming and drying effects resulting from climate change can increase the frequency and severity of fires (Jones *et al.*, 2020), and so in turn increase the risk they present to plant diversity. These intensifying conditions can also impact recruitment cycles and vegetation succession even in fire-adapted vegetation (Bowman *et al.*, 2014). In southern Australia, Forest Fire Danger Index values have been increasing since the 1950s, and current projections suggest that fire seasons will commence earlier and that fire events will be more frequent and more severe, and of longer duration (CSIRO & BOM, 2020; Mackey *et al.*, 2021). In 2019–2020, Australia faced unprecedented fires (Mackey *et al.*, 2021) where almost 19 million ha were burned (Filkov *et al.*, 2020). These extensive fires burned significant areas of land in the eastern part of the State of Victoria (Fig. 4), and their extent and ferocity may be a harbinger of a shift in fire regimes towards more severe events. Between 60 and 90 per cent of Victorian taxa were impacted by these fires (Gallagher, 2020). Ongoing recovery work was implemented by RBGV and the Department of Environment, Land, Water and Planning to collect seed and propagate accessions of the most threatened taxa.



**Fig. 4** Victorian bushfires burned over 1.2 million ha in the east of the State of Victoria between late 2019 and early 2020 (Godfree *et al.*, 2021), severely impacting both terrestrial and associated freshwater ecosystems such as this scene of the Genoa River. Photo: N. Clemann.

### *Pests and diseases*

Other stresses that may be affected by climate change include pests and diseases. Such effects may manifest as new pest incursions, increased severity of existing pest outbreaks, or conversely a reduction in the severity of existing problems (Pautasso *et al.*, 2012; Hunjan & Lore, 2020). In Australia, there are concerns about potential latitudinal and elevational range shifts under climatic change for *Phytophthora* spp. with special reference to alpine areas (Cahill *et al.*, 2008; Burgess *et al.*, 2019). The more commonly known *P. cinnamomi* already affects plants in mountainous South West Australia (Barrett & Yates, 2015). About 50 per cent of known pathogenic taxa in Australia are exotic species (Burgess *et al.*, 2019) and how some of these pathogens will interact with new suitable environments and hosts could reflect the

literal meaning of *Phytophthora* as ‘plant destroyer’.

In April 2010, myrtle rust (*Austropuccinia psidii*) was first reported in Australia (Carnegie *et al.*, 2010). This disease is limited to infecting taxa in Myrtaceae and damages soft plant tissues such as new shoots, leaves, flowers and fruits, resulting in leaf deformation and lesions, defoliation, reduced seed viability, dieback, stunted growth and ultimately death for some taxa (Pegg *et al.*, 2018). Australian taxa probably account for more than 50 per cent of the world’s species in Myrtaceae (ANBG, 2021). Myrtle rust is well established along most of the eastern coastal regions of Queensland and New South Wales (particularly in warm temperate, subtropical and tropical regions) and parts of the Northern Territory, and only marginally established in Victoria and Tasmania. Over 380 Australian taxa are potentially at risk from infection, with 43 severely affected

(Makinson *et al.*, 2020). The disease has impacted some relatively common species in their natural range so severely that two taxa (*Rhodomyrtus psidii* and *Rhodamnia rubescens*) are now listed as Critically Endangered (Makinson, 2018; Sommerville *et al.*, 2020). In April 2013, myrtle rust was first detected at RBGV’s Melbourne Gardens on *Lophomyrtus obcordata* (Fig. 5) and has since appeared on this and other host plants (mostly *Myrtus communis*, *Lophomyrtus* spp. and *R. rubescens*) for six of the last ten years – mostly in autumn. It is not clear whether climate change will increase the severity of this disease in Victoria as it requires suitable conditions of leaf wetness, hours of darkness and optimum temperatures to infect (Makinson, 2018). However, the optimum temperature range of 15–25 °C for development of myrtle rust and some climate niche models (Berthon *et al.*, 2018; Makinson, 2018; Narouei-Khandan *et al.*, 2020) suggest



**Fig. 5** A specialist team also involving horticulturists tackling the first myrtle rust incursion in Melbourne Gardens. Photo: P. Symes.

that global warming may provide new environments or seasonal shifts that support the proliferation of this disease in Victoria.

## The Landscape Succession Strategy

RBGV has included climate change responses in its strategic planning since the 1990s, particularly during the Millennium Drought of 1997–2010 (CSIRO, 2012). During this period, the organisation improved water-use efficiency and reduced water consumption by 40–50 per cent (Symes & Connellan, 2013), yet still safeguarded its living collections and landscape. Nevertheless, the publication of a series of climate change projections (CSIRO, 2008; Grose *et al.*, 2015) and the occurrence of alarming heatwaves (Department of Health, 2014) highlighted a need for more robust planning in response to climate change.

There were two questions to consider in justifying further plan development.

1. What was the actual risk to the living collections?
2. Could this risk be mitigated by microclimate-based plant selection?

Firstly, a preliminary climate audit of the living collection holdings was undertaken by horticulturists, which matched Köppen-Geiger climate classifications (Rohli *et al.*, 2015) with known plant distributions according to geographic zones defined by Brummitt *et al.* (2001). They found that about 35 per cent of taxa were considered to be at the highest level of risk from projected climate change (Symes, 2017). Secondly, a landscape microclimate analysis was carried out to determine if site selection could be used to mitigate temperature rise. It was concluded that cooling potential from most sites was inadequate to counter the more

extreme mean annual temperature increases of 3 °C projected by 2090 (Grose *et al.*, 2015; Symes, 2017). While selection of landscape microclimates can modify exposure to solar radiation and wind, and, to some extent, can mitigate the effects of more extreme temperatures, there are considerable constraints in applying this tactic across entire landscapes (Symes, 2017). These results indicated an urgent need to develop an integrated and strategic response to climate change.

In April 2016, the *Landscape Succession Strategy – Melbourne Gardens 2016–2036* was publicly released (RBGV, 2016). This 20-year strategy aims to respond to climate change risks by guiding the transition of Melbourne Gardens from existing plantings to a landscape collection better suited to the projected climate and environmental conditions of 2090.

Notably, horticulturists in Melbourne Gardens had a pivotal role in design workshops and in developing and writing the technical content of the Landscape Succession Strategy (LSS). Strategic plan development can involve significant input from consultants or other experts, and these financial costs may be perceived by some as limiting any planning for a climate future. Successfully involving horticulturists in such an important undertaking showcases the LSS as a realistic and valuable study of what is achievable for any arboretum or botanic garden.

Development of the LSS included seeking best practice examples of landscape adaptation plans through a worldwide literature review and obtaining industry feedback via forums such as LinkedIn Botanic Gardens Professionals (more than 5,000 members) and LinkedIn Horticulture (more than 40,000 members). This review revealed



a confronting gap in knowledge regarding effective strategic management of cultural landscapes and living collections through a climate change lens (Symes, 2017).

The LSS applies a paradigm for the managed change of the Melbourne Gardens vegetation. This model is based on ecological theories that define plant succession, such as changes in the composition and structure of vegetation communities over temporal scales following a disturbance threshold (Prach & Walker, 2019).

Key requirements identified by the LSS are as follows:

1. **Adapt the landscape and its living collections** to promote greater resilience for the projected 2090 climate.

2. **Act now** as the evaluation, selection and establishment of long-living assets such as trees require predictive decision making in advance of future conditions.
3. **Safeguard the educational, recreational and scientific value** of Melbourne Gardens for future generations.

Resilience has been defined as ‘learning how to change in order to stay the same’ (Walker, 2019). This is a prime goal of the LSS. When visitors arrive at Melbourne Gardens in 70 years’ time, they will experience a similar world-class landscape – one that retains its heritage character (Fig. 6), landscape qualities and plant diversity for future generations.



**Fig. 6** The heritage landscape of Melbourne Gardens as seen from Princes Lawn, developed by William R. Guilfoyle in the ‘picturesque’ landscape style following his appointment as Director of the Royal Botanic Gardens, Melbourne in 1873. This involved major landscaping work that was completed in 1879, but otherwise continued incrementally over a period of 35 years. Photo: P. Symes.

## *Implementation of the Landscape Succession Strategy*

### **Assessment of the climate change risk to the living plant collections**

In early 2017, researchers at the University of Melbourne were commissioned to analyse the climate risks faced by the living collections. Data sources included species occurrences from the Global Biodiversity Information Facility (GBIF) (GBIF.org, 2021), which currently holds over 330 million Plantae occurrences, 2,700 taxa from 400 urban plant inventories from cities around the world (Kendal & Farrar, 2017) and bioclimatic variables (BIOCLIM) from WorldClim (Hijmans *et al.*, 2005). BIOCLIM parameters (19 in total) are derived from monthly temperature and precipitation values to generate variables that define the climate envelopes of ecological niches (Pearson & Dawson, 2003; Booth *et al.*, 2014).

For Melbourne Gardens, the BIOCLIM parameters used in the analysis included: BIO1 – Annual Mean Temperature; BIO5 – Max Temperature of Warmest Month; BIO11 – Mean Temperature of Coldest Quarter; BIO12 – Annual Precipitation; and BIO17 – Precipitation of Driest Quarter (Kendal & Farrar, 2017). BIO1 – Annual Mean Temperature was used for the primary risk assessment as it was determined to be a robust proxy for enumerating temperature ranges of cultivated species (Kendal *et al.*, 2018). Other BIOCLIM values, such as BIO12 – Annual Precipitation, were selected to inform decision making. Precipitation has not been shown to be a strong predictor of climatic suitability in urban plantings and this risk is also deemed to be more manageable through irrigation (Kendal *et al.*, 2018).

The risk assessment examined the current climate, and RCP4.5 and RCP8.5 emission scenarios for climate projections in 2050 and 2070, including an estimate of urban heat

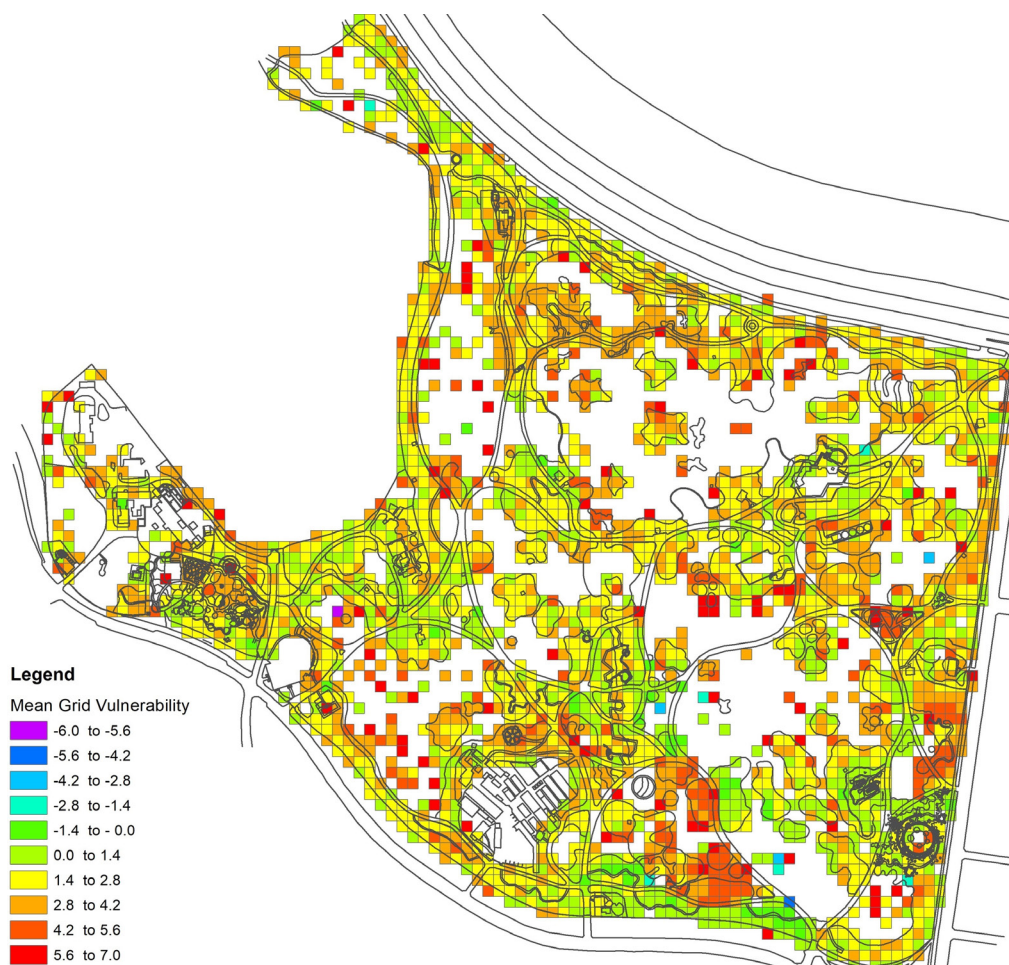
increase. For the relevant bioclimate variables, percentile distributions were calculated for natural and cultivated plant distributions. In the instances at which Melbourne's temperature scenario was warmer than the 90th percentile, taxa were considered at high risk from climate change, with highest risk allocated for taxa above the 97.5th percentile (Kendal & Farrar, 2017).

With temperatures as they are in 2021, about 12 per cent of the current taxa in Melbourne Gardens are ranked most at risk. For the projected RCP8.5 climate scenario by 2070, with an annual temperature of 19.3 °C, this risk increases to 26 per cent for all taxa assessed (Fig. 7) (Kendal & Farrar, 2017).

While these results and their spatial representation can appear alarming, they provide a useful tool for landscape planning. Identifying vulnerable taxa and spatial extents means proactive collection development and management can take place in advance of any potential decline of the holdings. Further, this assessment identifies new opportunities for plant selection, displays and research. As an example, another study commissioned by RBGV carried out a global climate risk analysis of rare and threatened plants and found that about 3,000 taxa were potentially well suited to the future climate scenarios for Melbourne (Kendal, 2017).

### **Global representation in the collection**

Strategic planning for the living collections sought to define the range of geographic regions with climatic parameters comparable to Melbourne's future. Spatial BIOCLIM layers of BIO1 – Annual Mean Temperature and BIO12 – Annual Precipitation (Fick & Hijmans, 2017) were processed in Geographic Information Systems (GIS) against spatial layers according to the World Geographical Scheme for Recording Plant Distributions

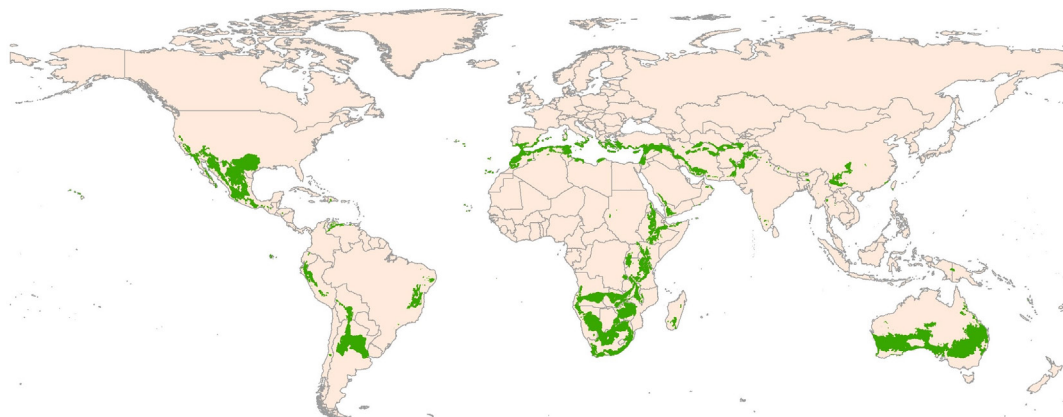


**Fig. 7** A spatial representation of Melbourne Gardens landscape risk in the extreme climate scenario of 2070, with an increase in mean annual temperature to 19.3 °C (Kendal & Farrar, 2017); red indicates the highest risk, green is considered an acceptable risk. Map: P. Symes.

(Brummitt *et al.*, 2001). This simple selection was based on an intersecting overlay comprising an annual mean temperature range of 17–21 °C and annual precipitation of 200–1,100 mm to highlight potential collecting zones (Fig. 8). Out of the top five countries, Australia has approximately 29 per cent of the potential climate-matched geographic area, while Argentina (9 per cent), South Africa (8 per cent), Mexico (8 per cent) and the USA (8 per cent) share about 33 per cent of the total. To inform decision making, these analyses using GIS layers can be

customised to combine different bioclimatic parameters, vegetation types, geography, biodiversity hotspots, and so on.

Furthermore, this analysis emphasises the capacity to assist with global plant conservation efforts. Some plant species may already be vulnerable to changing climatic conditions in their natural habitat and current *ex situ* collections in botanic gardens. For these taxa, Melbourne Gardens could provide a better growing environment now, or in the future, to safeguard plants threatened by rising temperatures in their original climates.



**Fig. 8** Map of world regions showing intersects of the following parameters: BIO1 of 17–21 °C, and BIO12 of 200–1,100 mm. Data sourced from Brummitt *et al.* (2001) and Fick & Hijmans (2017). Map: P. Symes.

## Case study: Australian Forest Walk

The Australian Forest Walk collection probably owes its origins to the strong interest of two eminent early Directors of RBGV: Ferdinand Von Mueller (Gardens Director 1857–1873 and collector of over 28,000 Australian voucher specimens) and William R. Guilfoyle (Gardens Director 1873–1909). Under Guilfoyle's directorship, the 'Australian Border' is believed to have been started in 1887 with a planting of 400 native trees and shrubs. Today, this collection of 1,395 accessions and 583 taxa covers almost one hectare and extends for half a kilometre along the southern boundary of the Gardens. However, the advent of the Millennium Drought (1997–2010), overall annual rainfall decline and projected climate change threaten the composition of taxa.

Current responses to climatic change include Australia-wide collecting expeditions on a scale not seen in over two decades, with the aim of diversifying holdings with more climate-suited taxa. GIS analyses of spatial layers of BIO1 – Annual Mean Temperature and BIO12 – Annual Precipitation (Fick & Hijmans, 2017) identified substantial areas in New South Wales (NSW) and Queensland.

The fine-tuning of these evaluations was undertaken by the horticultural curator, Gemma Cotterell (and others from RBGV), in collaboration with experts from other organisations including the Queensland Herbarium and the Royal Botanic Gardens and Domain Trust, Sydney. In early 2020, the first field expedition to NSW (Fig. 9) obtained about 60 taxa likely to be more suitable for cultivation in Melbourne. Some of these are dry rainforest species which are potentially less suited to other *ex situ* conservation techniques such as seed banking. Strong working relationships and sharing information have now led to positive safeguarding outcomes for threatened species across multiple states.

From her personal experience, Gemma states, 'In response to climate change we are undertaking collecting trips to forests of Australia that exhibit climates like those predicted for Melbourne's future. By planting wild-collected plants from a known provenance, I am transitioning the collection, and building the resilience of the Australian Forest Walk as well as the broader Melbourne Gardens landscape. I have collaborated with interstate botanic gardens and herbaria in

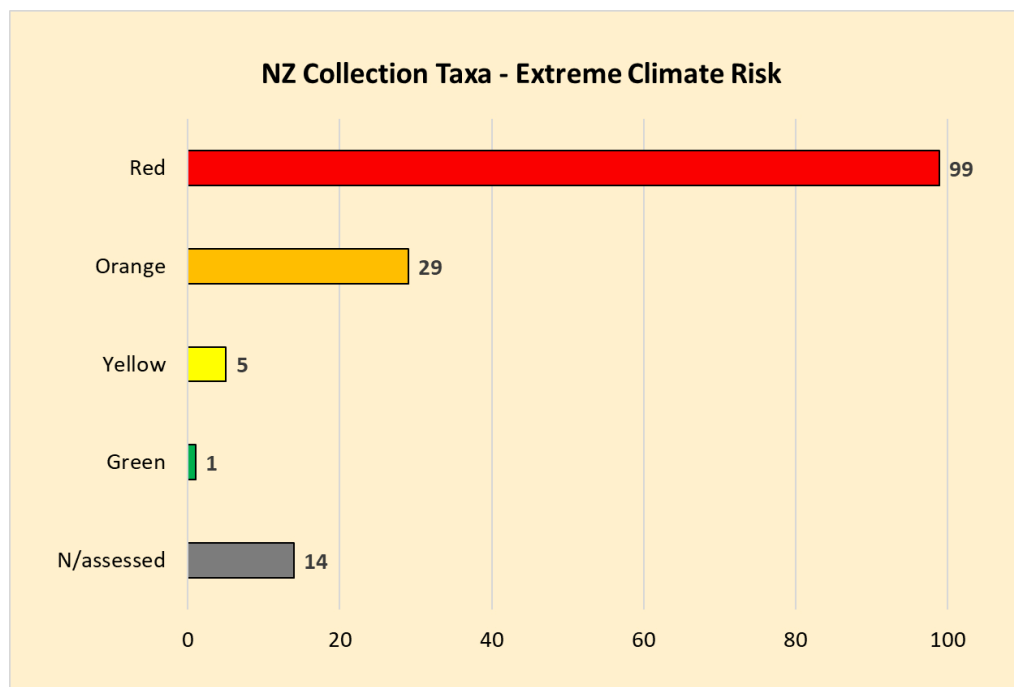
planning trips and sharing propagules as part of this work, supporting plant conservation efforts across Australia by aiding with seed banking, metacollections and bushfire recovery programs' (Gemma Cotterell, pers. comm.).

### Case study: New Zealand Collection

The collection of plants native to New Zealand has significant heritage importance as it was created as one of the last landscape developments of W.R. Guilfoyle (completed in 1908). Most species native to New Zealand originate from significantly cooler, wetter conditions than can be expected in Melbourne, both currently and in the future. Climate risk assessments highlighted the potential climate vulnerability of the collection as 67 per cent of taxa are considered at highest risk from temperature increases by 2090 (Fig. 10).



**Fig. 9** Gemma Cotterell collecting material from *Ixora beckeri* (brown coffeewood), Pikapene National Park in north-east NSW. Photo: G. Phillips.



**Fig. 10** A chart showing the climate risk for known New Zealand taxa (excluding cultivars) in the living collection against the extreme climate scenario of 2070, with an increase in mean annual temperature to 19.3 °C (Kendal & Farrar, 2017); red-coded results present the highest risk. Graph: P. Symes.

In response, the horticultural curator of the collection, Kate Roud, has built strong relationships with members of the New Zealand Plant Conservation Network and other botanic gardens in New Zealand to share information and expertise, and is working with Māori representatives to procure seed from habitat. For species currently impacted by heat, such as *Meryta sinclairii* (puka), Kate is also experimenting with different microclimate placements for some taxa to reduce the effects of excessive solar radiation and dryness.

Opportunities for these at-risk plantings include research programmes to identify actual taxon vulnerability and, perhaps more interestingly, consideration of the value of these collections and their plants as proxy indicators of climate change vulnerability to inform other colleagues in the species' countries of origin.

Climate change impacts upon plant biodiversity, and conservation of that biodiversity cannot be separated from indigenous people and their traditional knowledge (Cámara-Leret *et al.*, 2019; Wehi *et al.*, 2019). Kate has a deep understanding of this connection and states, 'The Aotearoa/ New Zealand Collection continues to teach me about climate change and culture. The connection of Māori people, culture and language to the earth and nature is deep and enduring. We, all of us, are "kaitiaki" – guardians. Papatūānuku, Mother Earth, is calling to us. It's time to listen and act.' (Kate Roud, pers. comm.).

### Key role of horticultural curators in climate change responses

Many botanical authors champion the role of botanical horticulturists in the field of 'botanical or conservation horticulture' and

the importance of supporting professional development in botanic gardens (Rae, 2013; Gratzfeld, 2017). In Melbourne Gardens, horticultural curators contributed significantly to the success of international ventures such as the Climate Change Alliance of Botanic Gardens (Martín *et al.*, 2020) and, to facilitate the development of collections, have effectively engaged with donors, senior executives and scientists from other organisations across the world. This horticultural capacity to engage at multidisciplinary levels of varying seniority is a strength when it comes to responding to climate change in an expedient and effective manner.

### Climate Change Alliance of Botanic Gardens

In its outreach aims, the LSS emphasised the need to 'improve understanding of the impacts of climate change on botanical landscapes' and to 'lead and facilitate networks and partnerships with relevant organisations in landscape-related conservation of biodiversity, human health, urban greening and water management' (RBGV, 2016).

### *Climate Change Summit and formation of the Climate Change Alliance of Botanic Gardens*

In December 2018, colleagues from a diversity of cultures, languages and organisations around the globe attended the botanical world's first Climate Change Summit, held at RBGV, Melbourne (RBGV, 2021a). The participants attended a series of presentations, workshops and field tours that had an emphasis on the impacts of climate change on plants and landscapes. It was clear that the profound complexity and

scale of addressing climate change requires global collaboration and the engagement of an abundant diversity of expertise – qualities that are intrinsic to a botanical gardens<sup>4</sup> network (Primack & Miller-Rushing, 2009; Martín *et al.*, 2020). In response to the now unavoidable changes in climate, it was agreed that the ‘time for action is now’, and a declaration was signed to ‘safeguard life by protecting landscapes’. This Melbourne Declaration led to the foundation of the Climate Change Alliance of Botanic Gardens (‘the Alliance’) (RBGV, 2021a).

### *Purpose and principles of the Alliance*

Botanic gardens worldwide are stewards of landscapes and living collections that are interconnected with critically important plant diversity. In responding to a recognised knowledge gap (Symes, 2017), the current focus of the Alliance is to build the global capacity of botanic gardens to safeguard landscapes and living collections through a changing climate.

Through biomimicry, plants and landscapes can provide useful regenerative models (Zari, 2018) to establish a network that remains contemporary to both the members and matters of concern. On this premise, the following principles of the Alliance were deliberately adopted from living systems models (Karl, 2012) to combine landscape sustainability, ecology and social networks (Opdam *et al.*, 2018). These principles are expected to nurture an Alliance that is adaptive, diverse and resilient, thriving in the face of boundless change.

#### **Principle 1 – self-organisation around a shared purpose**

Complex living systems exhibit a self-organising pattern in response to their environment (Negru, 2018). As part of a thriving, complex social-ecological system (Bodin *et al.*, 2016), this self-organising configuration in combination with a clear, shared purpose is expected to promote leadership that creates regional and global impacts.

#### **Principle 2 – recruit for and celebrate diversity**

In the context of botanic gardens, diversity is a readily identifiable characteristic of healthy natural and social systems (Dunn, 2017). Pursuing a high diversity of Alliance membership builds in adaptive capacity and support.

#### **Principle 3 – maintain momentum and energy flows**

Social networks are better assisted when an active rhythm is established to share expertise and resources concurrent with changing circumstances (Barnes *et al.*, 2017).

#### **Principle 4 – nurture relationships**

Social capital is built when the number and quality of relationships between members of the Alliance is increased (Sumanarathna *et al.*, 2020). Stronger relationships are likely to equate to a stronger Alliance (Fig. 11).

#### **Principle 5 – plan for resilience and adaptability**

The level of resilience and adaptive capacity (Walker, 2019) to maintain the goals and values of botanic gardens over time is a measure of success of these principles.

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<sup>4</sup>The terms ‘botanic gardens’ and ‘botanical gardens’ in this paper include botanic gardens, arboreta and other botanical landscapes that hold plant collections.



**Fig. 11** Some of the founding members of the Alliance sharing experiences with arborists and horticulturists of Melbourne Gardens during the Climate Change Summit. Even these informal discussions led to strengthening relationships beyond one event. Image: P. Symes.

### *Selected benefits of the Alliance* **Integrated and intergenerational context**

Arboreta and botanic gardens as typically urban landscapes can be defined as complex social-ecological systems (Martín-López *et al.*, 2017; Steenberg *et al.*, 2019). This intricacy is challenged by a changing climate, uncertainty and limited understanding of the future dynamics of shifting interactions. The Alliance brings a globally integrated wealth of cultural diversity, perspectives and expertise to assist its members with landscape and living collections management, and provides a line of sight between shared best practices. Technical improvements achieved by Alliance members are readily transferred and supported by 'social learning' (Dickson *et al.*, 2019). Social systems of learning can foster creativity, innovation and resilience, demonstrating high plasticity to predict needs, adapt to circumstances and adopt

new solutions within shorter time scales (Gonzales-Iwanciw *et al.*, 2019).

### **Plant conservation**

Collectively, arboreta and botanic gardens hold about 30 per cent of the world's known plants (around 106,000 species) and contain 41 per cent of threatened species through *ex situ* conservation, although there are significant collection gaps in plant groups such as tropical species (Mounce *et al.*, 2017). A global focus on the risks to vulnerable plants in collections and shared learning assists with the prioritising of further protection. There are also 'exceptional species' not suited for seed banking (Fant *et al.*, 2016) – rainforest species (some), cycads, oaks and palms – that need to be curated as living specimens to conserve unique genotypes. Threatened plants may already be at risk from changing climatic conditions in habitat and *ex situ* collections in botanic gardens, whereas a better growing environment could be



available now or in the future at other gardens and could be safeguarded through networked metacollections (Griffith *et al.*, 2020).

### Environmental protection and services

In addition to safeguarding plant biodiversity, the Alliance can mobilise protection for botanical landscapes and advocate for plant-based solutions to support human wellbeing (Shanahan *et al.*, 2015; Carrus *et al.*, 2017); maintain landscape carbon sequestration (Webb, 2014); provide natural cooling against temperature rise (Ellison *et al.*, 2017); provide habitat for urban biodiversity (Marselle *et al.*, 2019); reduce noise and filter pollution (Haase *et al.*, 2014); reduce damage from flooding and stormwater runoff (Livesley *et al.*, 2016); and contribute to resilient urban greening (Cavender *et al.*, 2019).

### Enhancing knowledge and expertise transfer through collaboration

Botanic gardens provide unique contexts for climate change research with geographically diverse plant holdings, managed plant environments, and long-term monitoring and considerable staff expertise (Primack & Miller-Rushing, 2009). Further, many plants are grown outside their natural range. This can demonstrate the 'fundamental niche' (Sax *et al.*, 2013) or the potential of a given species to grow beyond its natural distribution when competition, dispersal limitations and other inhibitory factors are removed (Bush *et al.*, 2018). Although cultivated environments may provide advantages for plant performance, species showing poor tolerance to climate change in these more favourable conditions could be even more at risk under the constraints of the natural habitat, for example species with specific germination temperature requirements (Sentinella *et al.*, 2020). Members of the Alliance can share

observations or organise custom research programmes to explore the tolerance range and to inform conservation priorities (Vincent *et al.*, 2020). Botanical collections can also be used as indicators of climate change vulnerability even for plants that may not yet be currently threatened. For example, founding Alliance members established the Ibero-American Node of Botanical Gardens against Climate Change (NIJAB-CC) to combine the expertise of Spanish-speaking countries in phenological research across continents, using latitudinal gradients to study plant lineages more sensitive to climate change, and improving meteorological data and climate change indices (Real Jardín Botánico de Madrid, 2020).

### Community and social profile

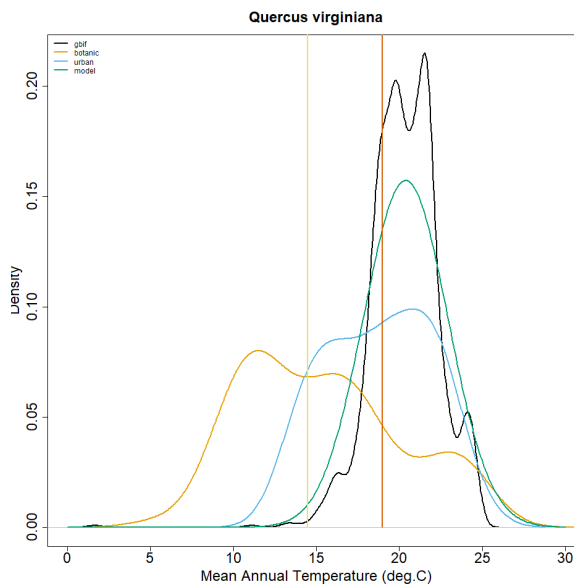
While botanic gardens have vast potential to communicate climate change issues and make societal impacts, it has been noted that they have lacked community visibility in this arena (Dodd & Jones, 2010). A partnership such as the Alliance provides a global prominence for all members, regardless of their capacity or resources. Since its formation, members have already mobilised the interest of their communities, influenced positive action by governments and energised botanical networks. During the Melbourne Climate Change Summit in 2018, Jerusalem Botanical Gardens received news of a significant private funding pledge that was linked to their involvement at the event. The Carlos Thays Botanic Garden of the City of Buenos Aires enabled a parliamentary declaration regarding climate change. In Australia, the government of Victoria initiated the 'Growing Victoria's Botanic Gardens' grant (AU\$4 million over 2019 and 2020) that includes improving the climate change adaptation and resilience of regional botanic

gardens (DEWLP, 2019). Opportunities abound to use botanic gardens as spaces to engage with the community through educational initiatives on climate change (Sellmann & Bogner, 2013) and citizen science (Chen & Sun, 2018).

### Flagship project: the Global Climate Risk Assessment Tool

There is currently no widely available tool to assist botanic gardens in assessing the climate suitability of current and potential species in their living collections. The Global Climate Risk Assessment Tool ('the Tool') project is a world-first initiative to support arboreta, botanic gardens, urban forestry and horticulture in decision making by providing climatic data and risk assessment in GlobalTreeSearch (BGCI, 2021). The Alliance is the lead agency working with Botanic Gardens Conservation International (BGCI), the University of Tasmania and RBGV. Along with the International Association of

Botanic Gardens, these organisations have provided direct funding and/or in-kind support. The Tool combines the strength of documented holdings of botanic gardens with species occurrences from GBIF and climatic inputs from WorldClim. About 17.7 million GBIF records have been linked to 48,481 distinct taxa, and 3,673 institutional gardens in the BGCI database have had their spatial location verified. The outcomes of the Tool are expected to include the following benefits: improved management of botanic gardens' living collections; reduced risk of long-term climate effects on long-lived species such as trees; more effective plant conservation through identification of climate-vulnerable species and suitable living collections for *ex situ* conservation; increased visibility and relevance of botanic gardens in urban greening; and new research opportunities in plant-climate science. The working prototype of the Tool (Fig. 12) was demonstrated through



**Fig. 12** An example of the preliminary results of the Global Climate Risk Assessment Tool prototype. The vertical lines represent Melbourne at mean annual temperatures of 14.5 °C and 19 °C. In this analysis, current occurrences of *Quercus virginiana* (southern live oak) are most frequent at temperatures of about 21 °C. This result may indicate that future warming in Melbourne will better suit its cultivation in the Gardens. Image: D Kendal.

workshops to Alliance members in February 2021 and is expected to be available to members in late 2021.

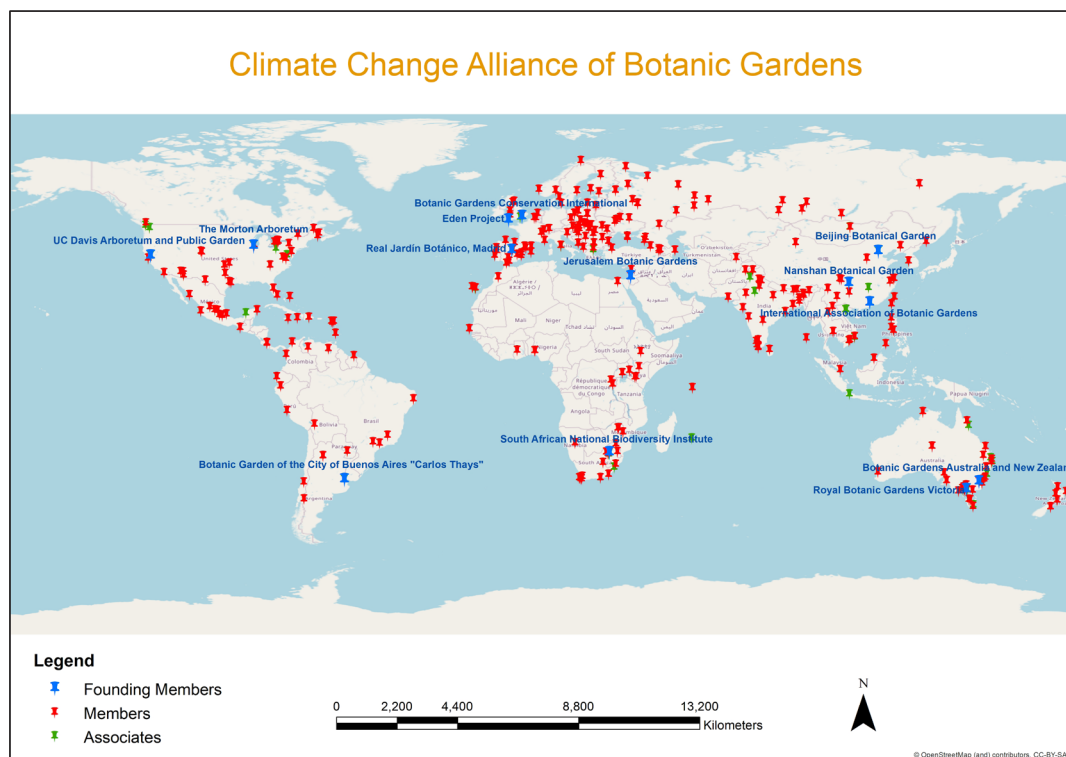
### Membership of the Alliance

Since its formation in December 2018, the Alliance has seen a rapid growth in membership. On 14 March 2021, there were 330 organisational and 71 associate members from 92 countries (Fig. 13). This progress builds on the Alliance principle: 'recruit for and celebrate diversity'. This overwhelming response in a relatively short time reflects the need for the Alliance and the desire for more capacity and collaboration on a global scale.

### Conclusion

Climate change is a global problem that transcends the boundaries of individual

arboreta and botanic gardens. Furthermore, plant distribution is often not constrained by political limits as natural habitats can extend across regions and countries (Enquist *et al.*, 2016), and even further for those taxa held in the living collections of botanic gardens worldwide. When this enormous spatial scale is combined with the complexity and uncertainty of the future, it requires both a diversity of expertise and perspectives and the collaboration of many organisations to effectively respond to issues (Schulman & Lehvavirta, 2011). No botanic garden can fully tackle these problems on its own, especially those that have fewer resources. Collaboration provides a powerful mechanism to pool resources, share skills and insights, and provide greater reach towards tackling climate change and mitigating its many potential outcomes. What the future holds



**Fig. 13** Current spread of membership of the Climate Change Alliance of Botanic Gardens worldwide. The founding members are shown by blue pins and text. Map: P. Symes.

is yet to be discovered, but many plants face unencountered climate risks: 'In the next 50 years, 20–50 per cent of current plant species in botanic gardens and urban landscapes will likely confront temperatures those species have never experienced before' (Dr D. Kendal, University of Tasmania, pers. comm.). In facing this climate change emergency, botanic gardens have the depth of proficiency and community of practice across the globe to meet these challenges (Manuti *et al.*, 2017; Entwisle, 2019).

Learn more at <https://www.rbg.vic.gov.au/initiatives/climate-change-alliance>

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