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Adapting the botanical landscape of Melbourne Gardens (Royal Botanic Gardens Victoria) in response to climate change

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A B S T R A C T

Botanic gardens around the world maintain collections of living plants for science, conservation, education, beauty and more. These collections change over time – in scope and content – but the predicted impacts of climate change will require a more strategic approach to the succession of plant species and their landscapes. Royal Botanic Gardens Victoria has recently published a 'Landscape Succession Strategy' for its Melbourne Gardens, a spectacular botanical landscape established in 1846. The strategy recognizes that with 1.6 million visitors each year, responsibility for a heritage-listed landscape and the need to care for a collection of 8500 plant species of conservation and scientific importance, planting and planning must take into account anticipated changes to rainfall and temperature. The trees we plant today must be suitable for the climate of the twenty-second century. Specifically, the Strategy sets out the steps needed over the next twenty years to transition the botanic garden to one resilient to the climate modelled for 2090. The document includes a range of practical measures and achievable (and at times somewhat aspirational) targets. Climate analogues will be used to identify places in Australia and elsewhere with conditions today similar to those predicted for Melbourne in 2090, to help select new species for the collection. Modelling of the natural and cultivated distribution of species will be used to help select suitable growth forms to replace existing species of high value or interest. Improved understanding of temperature gradients within the botanic garden, water holding capacity of soils and plant water use behaviour is already resulting in better targeted planting and irrigation. The goal is to retain a similar diversity of species but transition the collection so that by 2036 at least 75% of the species are suitable for the climate in 2090. Over the next few years we hope to provide 100% of irrigation water from sustainable water sources, and infrastructure will be improved to adapt to predicted higher temperatures and more climatic extremes. At all times there will be a strong focus on assisting the broader community in their response to climate change.

1. Introduction

Over coming decades, the southern Australian city of Melbourne is likely to experience more extreme hot days in summer, less rainfall overall and more 'tree-toppling' storms (Australian Bureau of Meteorology, 2016, Figs. 1 and 2). Based on annual average temperatures projected for 2090, currently temperate Melbourne is expected to be warmer than present-day Sydney (a subtropical city, 870 km to the north-east), and more like Algiers in northern Africa, central China or the inland Australian town of Dubbo (Figs. 3–6).

Melbourne Gardens, one of two botanic gardens managed by the Royal Botanic Gardens Victoria (the other is Cranbourne Gardens, including the award-winning Australian Garden), is universally recognised as one of the most beautiful and stunning botanical landscapes in the world. For 170 years it has been home to a diverse collection of plants from across the globe, some of them rare and threatened with extinction, others awe-inspiring for their size, beauty or botanical curiosity. As custodians of this living masterpiece, the Royal Botanic Gardens Victoria has to plan for more than the next few years. Our 'planning horizon' should be calibrated more towards the life of a tree – a century or two. On that scale, climate change looms large. In 2002, the Royal Botanic Gardens Victoria embarked on an ambitious project (Working Wetlands) to collect, treat and distribute storm water from within and around

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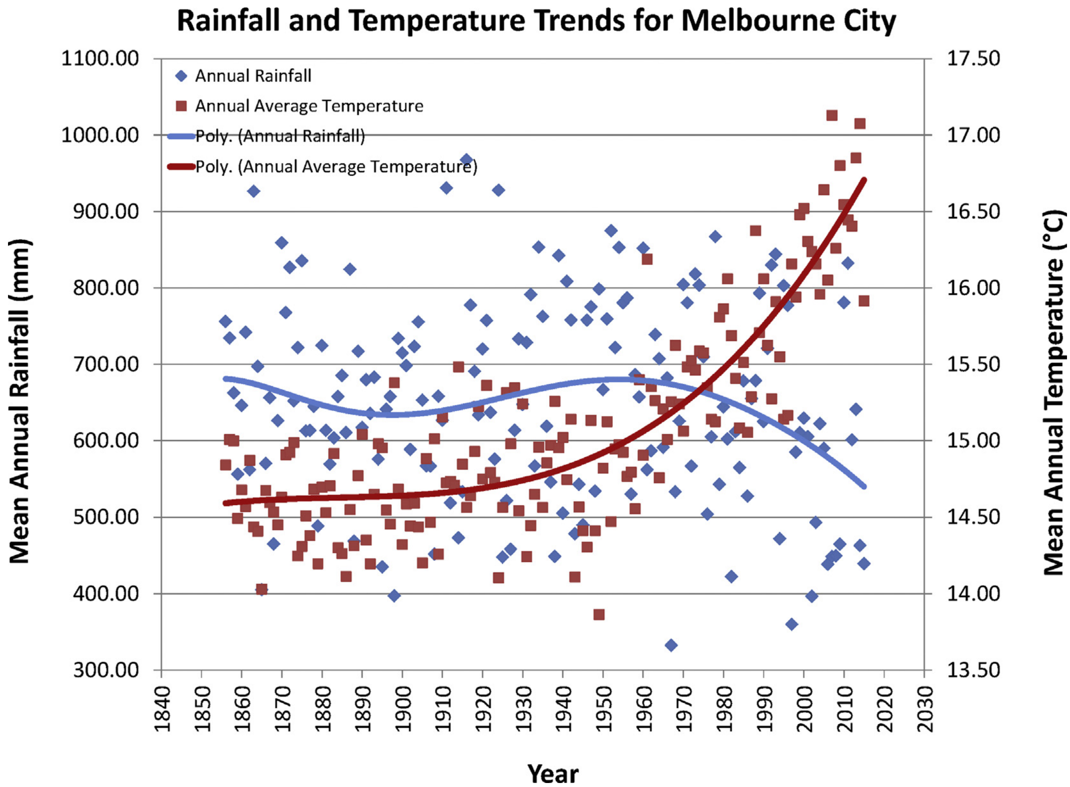


Fig. 1. Rainfall and temperature for the city of Melbourne 1855–2015. Data from Australian Bureau of Meteorology (2016).

Group	Parameter	Averaged	Now	+/-	2090
Temp.	Annual Mean (°C)	1986-2005	**15.9**	+3.1	**19**
	Mean Days >35 (°C)	1981-2010	**11**	+13	**24**
	Annual Mean Max.(°C)	1986-2005	**20.4**	+3.3	**23.7**
Rainfall	Annual Mean (mm)	1986-2005	**624**	-9%	**574**
	Winter Mean (mm)	1986-2005	**147**	-10%	**132**
	Spring Mean (mm)	1986-2005	**180**	-19%	**146**

Fig. 2. Current climate and that predicted for Melbourne in 2090. Data from Australian Bureau of Meteorology (2016) and Grose (2015).

the Melbourne Gardens. The combined infrastructure of a wetland filtration system, water treatment centre and complementary landscaping confirmed our reputation as world leaders in integrated water management. In 2016, we took the next step, adapting our living collections and landscape to the likely impacts of climate change.

2. Landscape Succession Strategy

2.1. Context and content

The *Landscape Succession Strategy* (Royal Botanic Gardens Victoria, 2016, Fig. 7) is a natural extension of the Working Wetlands project, guiding our transition to a botanic garden suited to the projected climate and environmental conditions of 2090 while retaining the Gardens' heritage character, landscape qualities and species diversity. Ambitious but achievable targets are set, including the kind of research and data needed to make evidence-based decisions. While no doubt you'll see more drought tolerant plants in Melbourne Gardens, it's not all about cacti and succulents. It's also about planting with new temperature regimes in view— ‘heat tolerance’ will need to become more part of the Australian plant selection vernacular! The Happy Tree (or Xi Shu; *Camptotheca acuminata*) beside the William Tell Rest House and the Rainbow Gum (*Eucalyptus deglupta*) at the end of Fern Gully are both water-loving trees doing very nicely beside our lakes. On the other hand, the Mexican Blue Palm (*Brahea armata*), prominent in the Guilfoyle's Volcano landscape, is a good example of an attractive and unusual plant we would recommend for drier situations. The Forest Elder (*Nuxia floribunda*) from Africa is expected to withstand the predicted higher temperatures but as a typical riparian species would likely require a situation with some available water. Each species is to be assessed on its merit, using the best available information on its climate preferences and tolerance,

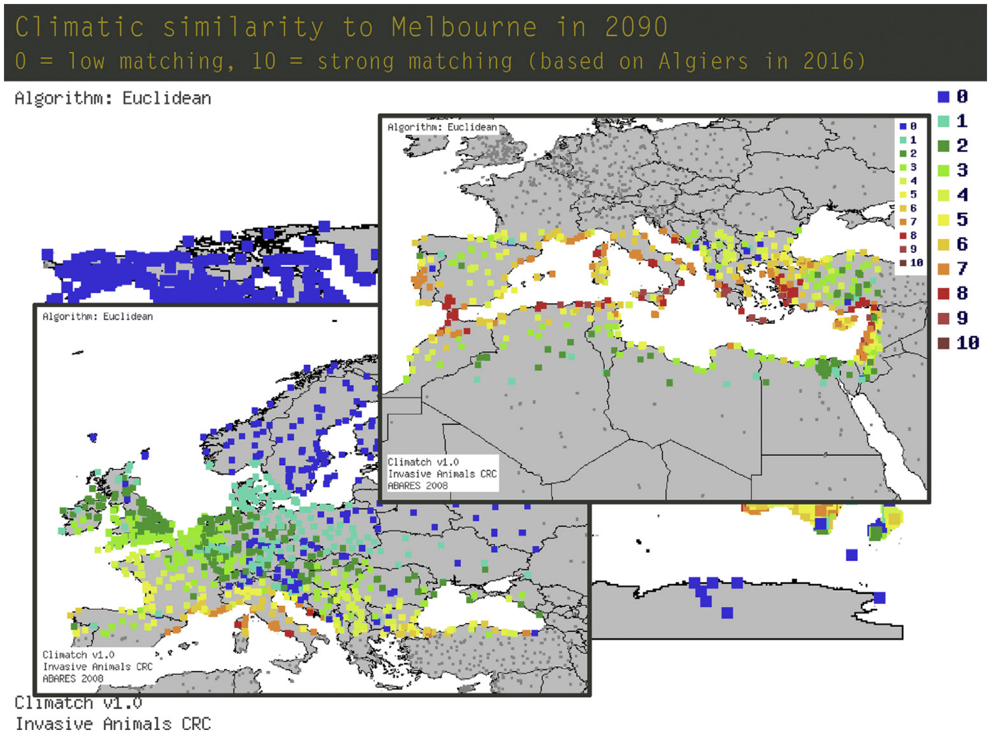


Fig. 3. Similarity between climates in Europe today with the predicted climate in Melbourne in 2090. Data from ABARES (2008).

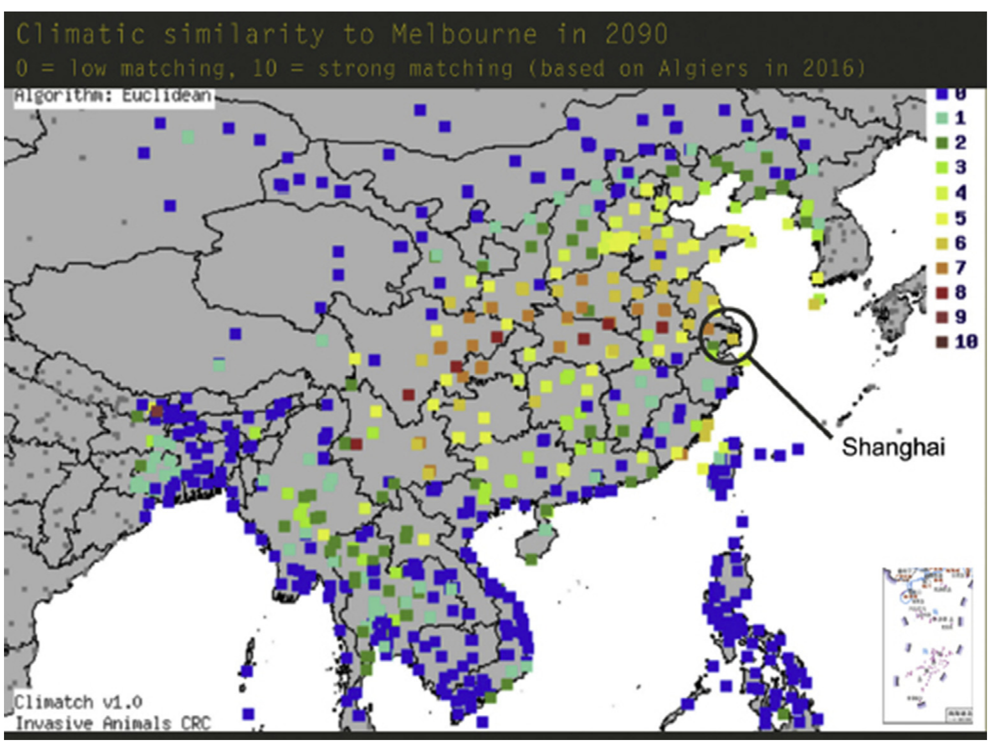


Fig. 4. Similarity between climates in China and nearby Asia with the predicted climate in Melbourne in 2090. Data from ABARES (2008).

as well as the very best botanical and horticultural experience and expertise.

Aside from the choice of species, we have to manage competition from established specimens, tend our soil, and capture and store as much water as possible. A changing climate can also bring biosecurity threats – new pests and diseases, as well as increased virulence of those already among us – and increased wear and tear on our built landscape, including the magnificent shelters and the graceful, but now very cracked and lumpy, paths. We'll continue to work with other botanic gardens throughout Victoria, Australia and internationally, to conserve particular examples of our rare and threatened flora, already under threat from loss of habitat,

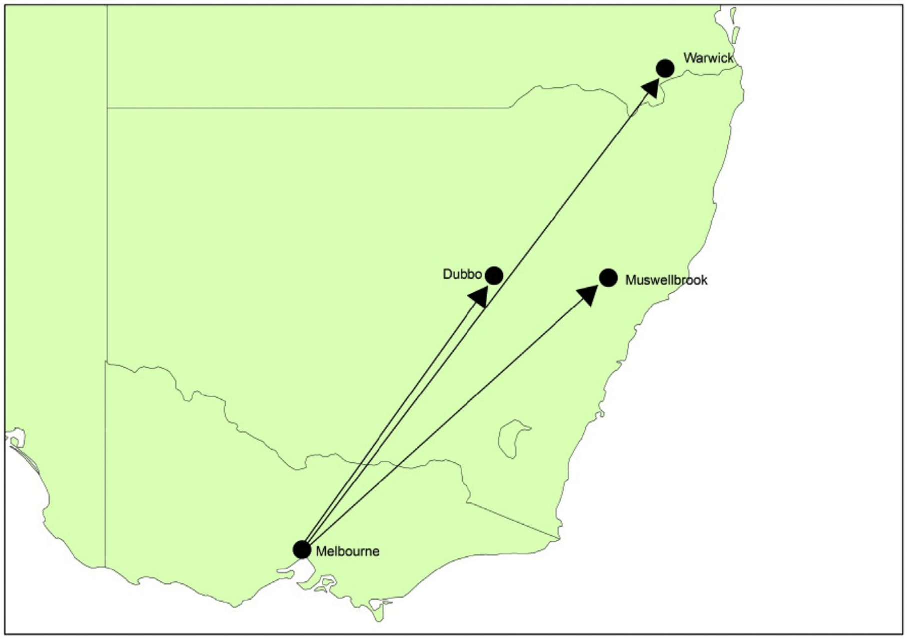


Fig. 5. Towns in Australia with climates similar to those predicted for Melbourne in 2090. Data from Australian Bureau of Meteorology (2016).

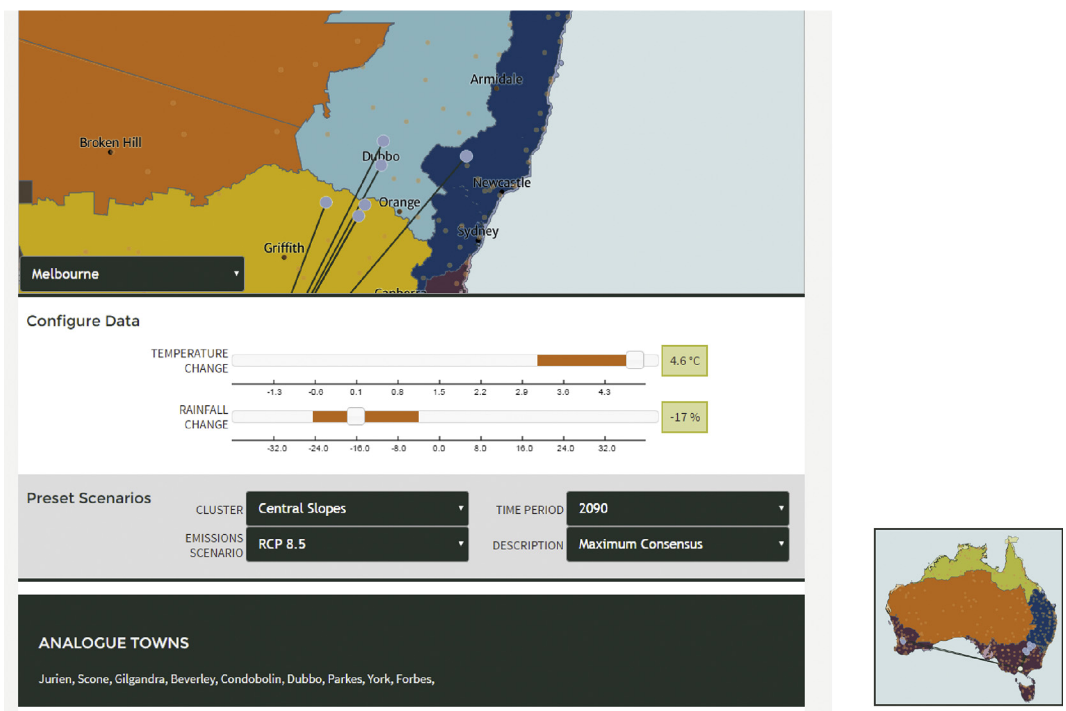


Fig. 6. Detail of map showing towns in Australia with climates similar to those predicted for Melbourne in 2090. Data from Australian Bureau of Meteorology (2016).

encroaching weeds and antipathetic land management. Climate change only adds to the urgency for seed banking, propagation, interpretation and restoration.

Any change to the climate presents a significant threat to a garden growing plants outside their natural range, but with careful plant selection and expert horticultural care we can transition the landscape to one more suited to Melbourne's emerging climate. Familiar plants can be moved to new locations and new and equally beautiful species added to the palette. The *Landscape Succession Strategy* is the first of its kind for botanic gardens in Australia, and possibly the world; it is set to become a blueprint for other botanic gardens planning for climate change adaption.

2.2. Strategies and targets

Five strategic targets have been set to meet five strategic goals:

(1) *Actively manage and transition the Melbourne Gardens landscape and plant collections*
By 2036, 75% of taxa in the Gardens will be suited to the projected climate of 2090 (this target does *not* preclude the

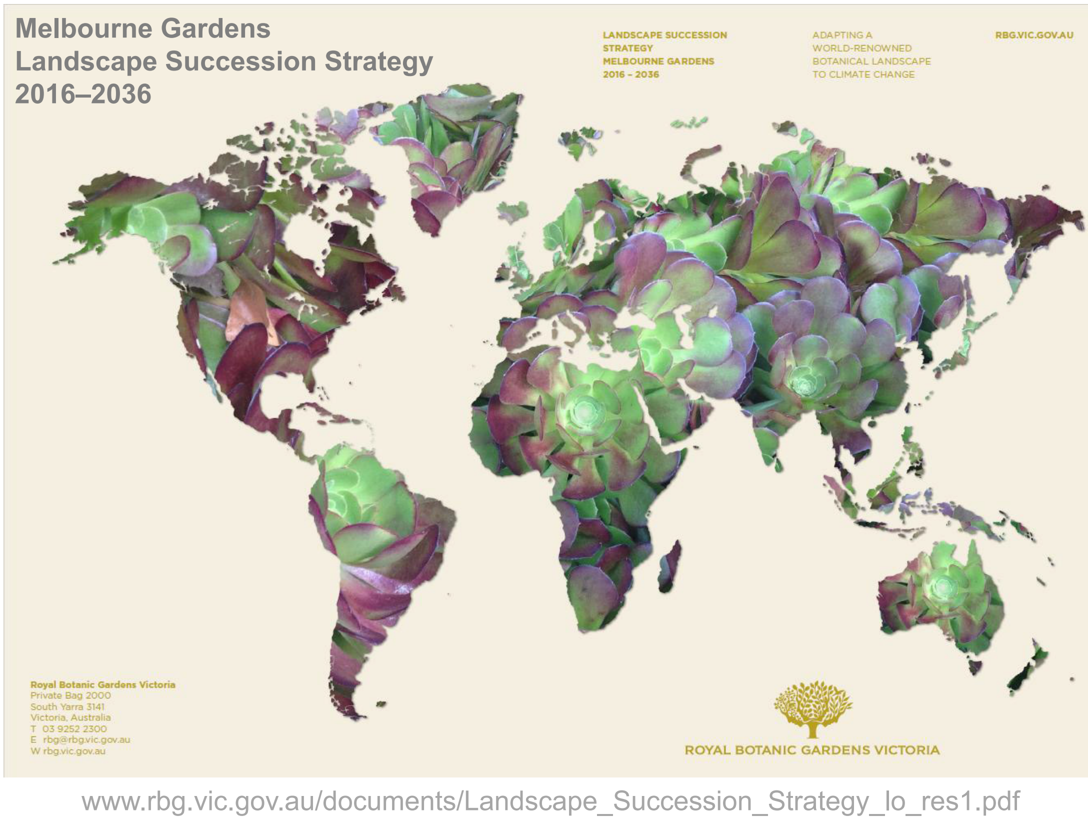


Fig. 7. Cover of *Melbourne Gardens Landscape Succession Strategy 2016–2036*.

growing of plants in microclimates – for example, near water bodies or in glass and shade houses – that would allow them to tolerate otherwise more extreme conditions).

(2) *Establish a mixed-age selection of plants composed of a diversity of taxa*
By 2036, plant diversity will be equal to or greater than the current 8400 taxa, of variable age, and including greater than 35% wild provenance-sourced plants (an increase on the current percentage of 20%).

(3) *Maximise sustainable water availability and use*
By 2020, 100% of landscape irrigation needs will be provided by sustainable water sources.

(4) *Maximise the benefits of the green space and built environment through landscape design*
Any new green and built infrastructure will be capable of mitigating and withstanding predicted climatic extremes.

(5) *Improve understanding of the impacts of climate change on botanical landscapes*
The Royal Botanic Gardens Victoria will continue to demonstrate that life is sustained and enriched by plants, and to encourage and facilitate climate change as a key consideration in planning and managing 'green space'.

2.3. Major challenges

In planning for a transition to the projected climate of 2090, the following challenges have been identified:

- *Adapting to significantly higher temperatures and lower rainfall*
By 2090, the climate for Melbourne is projected to be hotter (+3 °C in Mean Annual Temperature) and drier (−9% Mean Annual Precipitation), with an increased probability of extreme events such as heat waves and floods (Webb and Hennessy, 2015; RCP 8.5 scenario). Prior to the 1950s, Melbourne City's Mean Annual Temperature was 14.7 °C (1856–1949) rising to 16.1 °C for the last 30-year period of 1986–2015 (Australian Bureau of Meteorology, 2016). Managing water scarcity is a relatively easier task (if resources are not limiting) however, bandwidth increases in ambient temperature and frequency of very hot days cannot be readily mitigated at the landscape scale and a shift towards higher temperature suited taxa will be essential.
- *Managing and securing sustainable water supplies*
Through water use efficiency programs in place since 1994, Royal Botanic Gardens Victoria has already reduced its annual landscape water demand in Melbourne Gardens by over 50% (or 70% if stormwater use offset is included). However, all the cost-effective stormwater catchments are now in full use to recover urban runoff. Groundwater supplies are considered too limited and saline for landscape irrigation. The remaining options include reuse of waste water – i.e. sewage or saline water – but these have very high capital and operating costs (although they may become economically competitive during the life of the Strategy). Currently the most feasible option being considered is sourcing water from the nearby Yarra River, upstream of the tidal influence, and through a 'buy back' of an existing but no-longer used water licence where most of the water will return to environmental flows but some to landscape irrigation. This scheme is being considered as a precinct-wide option in this part of Melbourne, which also includes many other iconic greens spaces within the city.
- *Maintaining the values of an ageing, mature, heritage landscape through this transition*
Cultivated landscapes — even those of heritage character — are in a state of constant flux due to intrinsic dynamics of the living (e.g. tree ageing and dying) and built (e.g. paths and buildings) environment, but also changing expectations around their use

and values, and now (and perhaps always) a changing climate. A major challenge is perception – it is easy for the visitor to think that what they see is what has always been. Interestingly, an examination of old photographs from W R Guilfoyle's tenure (1873–1909) as Director and principal landscape designer of Melbourne Gardens appears to show a more austere and xerophytic landscape. Which makes sense when we consider the water supply challenges of those times. However visitors today tend to view any shift to more drought-tolerant plants as straying from the original intent of Guilfoyle's stunning creation. Our focus today is protecting the heritage, picturesque landscape *style* rather than on maintaining specific, unsuitable taxa. That said, we can sometimes source variants of existing species more suited to our emerging climate but recollecting (from different populations in the wild) or horticultural selection. We have commissioned a more detailed analysis of the future climate vulnerability or resilience of our current species which, when used in combination with a 'useful life expectancy' tree assessment (Callow, 2011), will support planned removals and replacement of declining or unsuitable specimens. As an aside, and related to perceptions, it surprises many visitors to learn that over 50% of all trees in Melbourne Gardens are Australian-native, despite the 'exotic feel' of the landscape (largely because people forget that Australia has many subtropical and wet forest tree species suitable for horticulture). Fortunately, some of the more landscape significant species (e.g. *Araucaria* and *Ficus* species) are not only Australian-native but also likely to be suited to the predicted climate in coming decades.

- *Responding to biosecurity threats from increasing globalisation and changing environments*
Changes to environmental conditions may predispose the landscape to threats from new exotic pests (Pautasso et al., 2012). Due to the changing climatic baseline, it's not always easy to predict new incursions or whether the conditions will support their establishment. When this is combined with increased visitation and national importation of commodities, there is increased risk of a new pest inadvertently being introduced to damage our collections. Royal Botanic Gardens Victoria works work closely with government agencies charged with plant biosecurity to reduce these risks. For example, Melbourne Gardens with its high plant diversity and relative proximity to shipping docks and airports is currently used as an 'early warning' sentinel site by biosecurity officers through installing trapping systems to detect new pest incursions.
- *Managing ageing built-assets*
With over 100 buildings (many of them of high heritage value) and an ageing infrastructure of utilities and paths, the built assets within Melbourne Gardens present a myriad of challenges in a changing climate. The design and condition of the stormwater system, for example, is poorly suited to deal with the increasing risk of extreme weather events such as high intensity rainfall causing overland flow and waterlogging. Works are already in progress to rectify some of these problems but even a more recent asset, like the automatic irrigation system installed in 1993–94, is in part nearing the end of its useful life. In large open plaza areas, we need to respond to anticipated higher temperatures through creative building and landscape design. In 'cool zones', like our Fern Gully, we can add new resting places to provide relief from extreme conditions.

2.4. Progress

The *Landscape Succession Strategy* represents a pit-stop on a much longer journey: a time for reflection and a time to take stock of what we value and wish to maintain. Apart from the water conservation (Working Wetlands) project we have already begun to audit our living collections to assess their likely viability in a changing climate.

So far we've plotted rainfall requirements for selected tree species by sourcing information from Simpfendorfer (1992) and Boland et al. (2006) and comparing with historical rainfall and water allocation targets Australian Bureau of Meteorology (2016; Fig. 8). This doesn't provide an absolute tolerance range but it is indicative of the kind of rainfall pattern they will tolerate.

We can also look for correlations between a plant's natural distribution and the projected climate in Melbourne in 2090: Fig. 9 uses *Lophostemon confertus* and bioclimatic estimates of Mean Annual Temperature and Mean Annual Precipitation (Atlas of Living Australia, 2016). Provenance-targeted plant selection can be used to indicate eco-types with greater tolerance to future and current climates. Most recently we have sourced and propagated seed from a population of *Corymbia maculata* from the state of Victoria, rather than where most previous collections have been made, New South Wales. This Victorian population is likely to tolerate conditions closer to those experienced in Melbourne today and later this century.

Worldwide, the Global Biodiversity Information Facility (2016) is another web-based platform that can be used to map plant distributions. The 'explore species' under the 'data' tab can be used to generate all recorded occurrences, many of which appear to be linked to coordinates. GBIF can include cultivated distributions (i.e. plants grown in cities) and these may conceivably be used as analogues for determining the risks of susceptibility or potential resilience within a climatic range, especially in regard to temperature. In turn, taxa that are deemed resilient could be used as analogous species to identify other potentially suitable plants that are typically associated within the same ecological niches. We have cross-linked geospatial layers such as MAT and MAP (Hijmans et al., 2005) with recorded coordinates of certain taxa to analyse rainfall and temperature ranges. However, this information has to be used with caution. *Cedrus deodra* (distribution from Global Biodiversity Information Facility, 2016; climate modelling from Worldclim, 2016, Fig. 10) may not do particularly well in the climate currently experienced by Melbourne yet young and old trees thrive in the Melbourne Gardens today. This is perhaps an example of a plant extending well beyond its presumed ecological niche due to reduced competition from other species and influences in its natural habitat (Gallagher et al., 2010). With this strong caveat in mind, our analysis so far shows that around 35% of our collections are unlikely to be suited to the climate in 2090 (Fig. 11).

Lam et al. (2016) mapped the microclimate (relative humidity and temperature) at 18 locations across Melbourne Gardens to assist in landscape planning (Fig. 12). It was found that for warm days, 30 °C or above, Fern Gully was up to 6 °C cooler in maximum temperature than Melbourne City. This was expected but interestingly our Oak Lawn, a woodland setting with large mature trees and mown turf, also attained similar temperature readings. This supports the findings of Shashua-Bar et al. (2009) on the synergistic cooling relationships between irrigated turf and shading by overhead tree canopies. Mean air temperature differences on selected warm days for Fern Gully and Oak Lawn were 2.7 °C and 2.1 °C cooler respectively than Melbourne City. The data highlight areas we can promote to visitors on very hot days (e.g. above 40 °C) and areas we can develop for better human thermal comfort (Norton et al., 2015).

Another important initiative has been to establish Irrigation Scheduling classes. By defining areas requiring different irrigation schedules, from not irrigated through to requiring regular irrigation (Class A), we can maximise the impact of the limited water resources we have available during dryer months (Fig. 13).

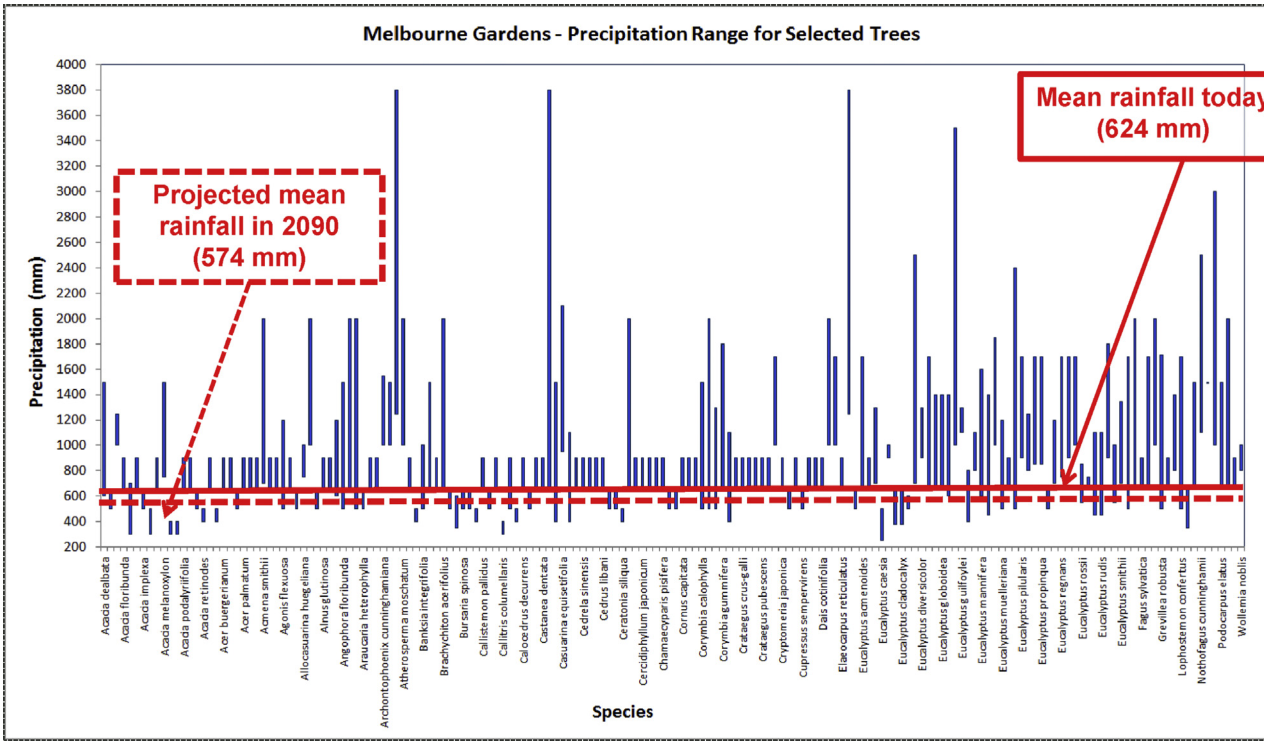


Fig. 8. Precipitation range for selected trees in Melbourne Gardens. Data from Boland et al. (2006) and Simpfendorfer (1992).

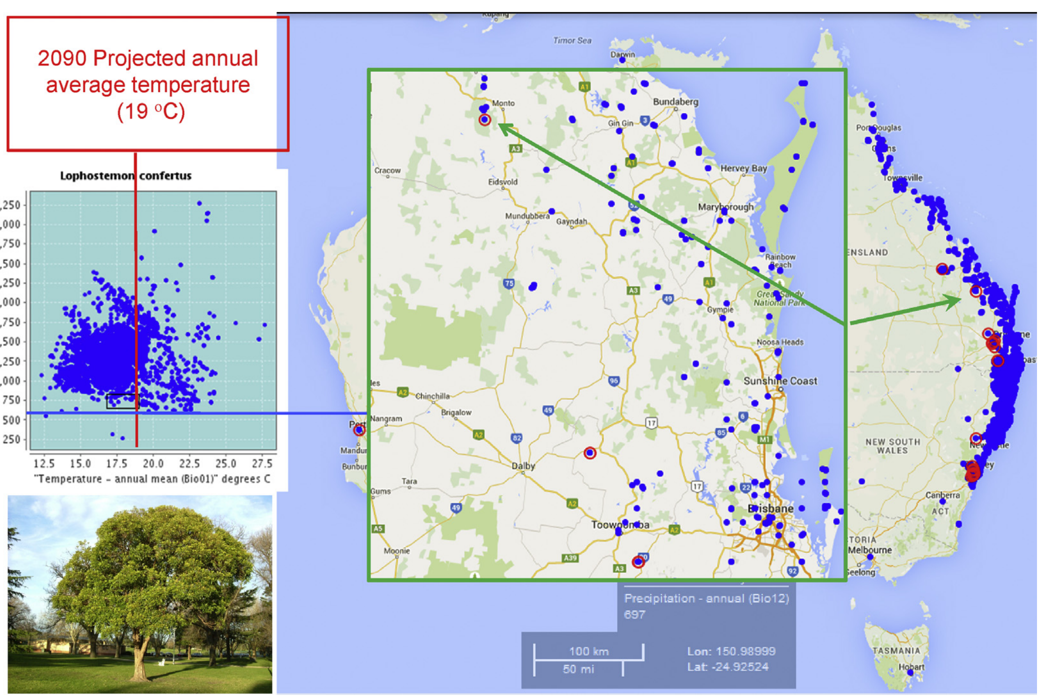


Fig. 9. Example (*Lophotstemon confertus*) of how the recollection of more suitable genotypes can be planned based on distribution mapped against climate parameters. Data from Atlas of Living Australia (2016) and Australian Bureau of Meteorology (2016).

There are other ways we have begun to respond to climate change and pre-empted the targets in the *Landscape Succession Strategy*. A few other examples are:

- Duplication and transfer of susceptible wild-collected Southern Chinese collections to the National Rhododendron Garden in the nearby Dandenong Ranges (a site more likely to retain conditions suitable for these species)
- Commencing research into 'water-banking' in subsoil (more than two Ornamental Lakes worth of water can potentially be stored in winter-spring for later use)
- Commencing post-graduate research on human thermal comfort of botanical landscapes, and the development of plant evaluation and selection for one of the major collections
- Supporting staff travel to other botanic gardens to identify suitable future taxa and procure material (e.g. Adelaide, Jerusalem)

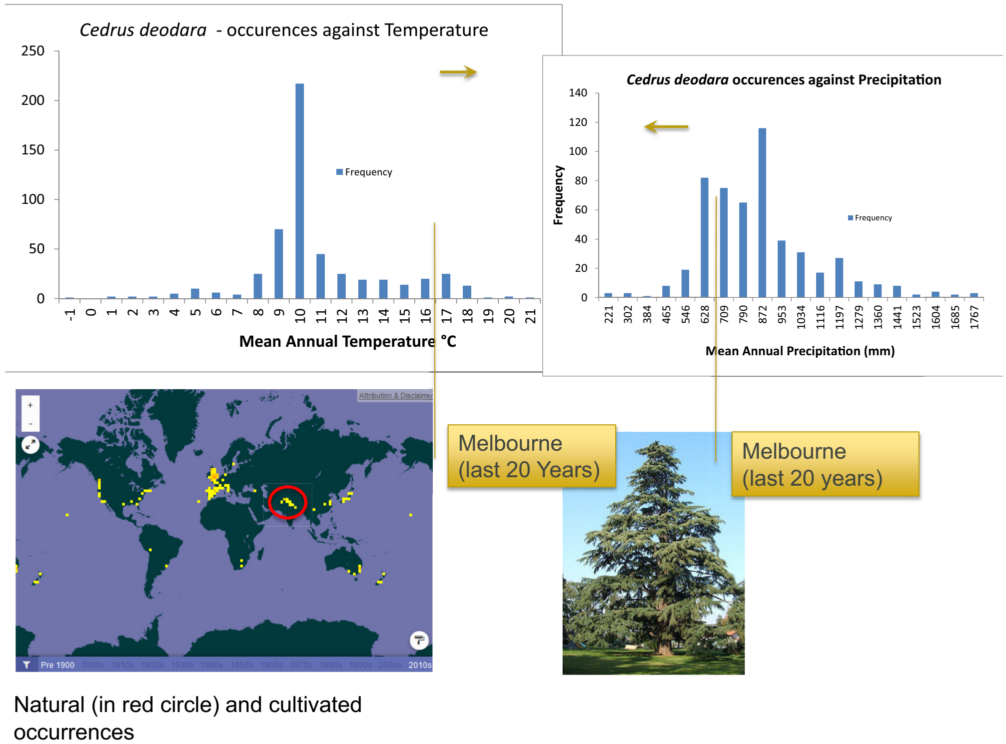


Fig. 10. Example of a species (*Cedrus deodara*) growing outside its predicted climate envelope. Data from Global Biodiversity Information Facility (2016) and Worldclim (2016).

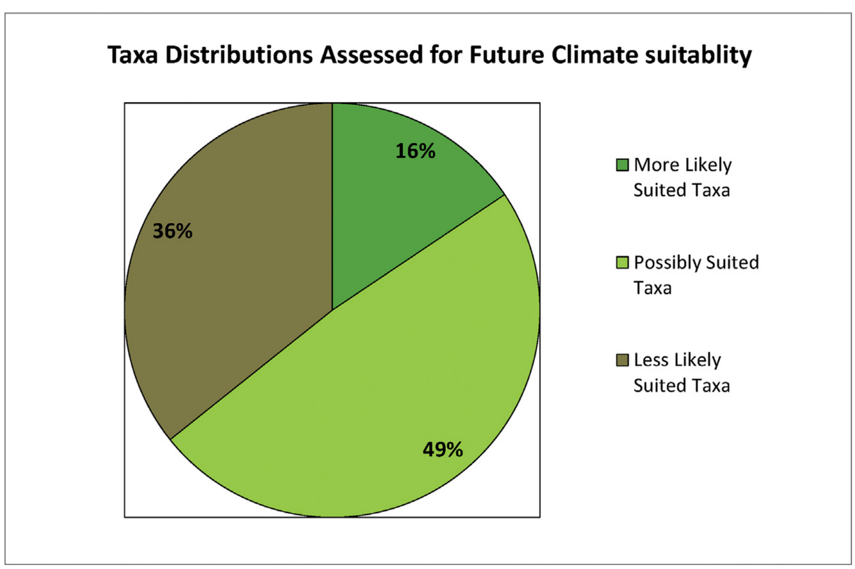


Fig. 11. Proportion of taxa growing currently in Melbourne Gardens suitable for the climate predicted in Melbourne in 2090 (based on those taxa assessed to date).

- Encouraging conference attendance and presentations relevant to the impacts of climate change on botanic gardens; and
- Sharing research project with University of Melbourne on developing a landscape carbon accounting model to understanding the current storage and rates of carbon sequestration (Webb, 2014).

Of course there is much to do, including sourcing alternative sources of irrigation water to further supplement potable water use beyond our current levels of up to 40% from recycled storm water and a more thorough understanding of the horticultural requirements of our collection. This last point is a critical one and plays to the strengths of botanic gardens generally: the keeping of records, encouraging horticultural excellence in our employees and volunteers, and decision making based on the very best evidence available. We can always do better and the *Landscape Succession Strategy* will keep us focussed on the long-term maintenance of the living collections and their landscape.

Site	[1]Max. Air Temp. (°C)	[1]Av. Max. Air Temp. (°C)	[2]Overall Average Temp (°C)	[1]Av. Variation from Melb.City (°C)
Volcano	44.4	35.8	20.7	-1.4
Grey Garden	44.0	35.6	20.5	-1.6
O Gate	44.1	35.5	20.3	-2.0
Western Lawn (Iris Bed)	44.3	35.7	20.0	-2.4
Tearooms	43.3	34.8	20.1	-2.4
Rockery Bed	43.3	34.9	19.6	-3.3
William Tell Bed	43.8	35.4	20.2	-2.5
A Gate	42.8	35.0	20.2	-2.1
Cassine Bed	42.7	34.5	19.9	-2.6
Oak Lawn	41.9	33.3	19.6	-2.9
Fern Gully	41.2	32.5	19.3	-3.7

[1] 28 days > 30°C, 19/12/2013 to 26/3/14
[2] All days from 19/12/2013 to 26/03/14

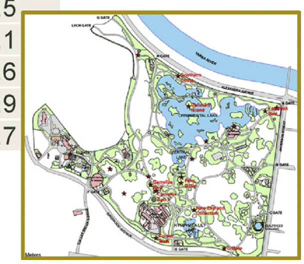
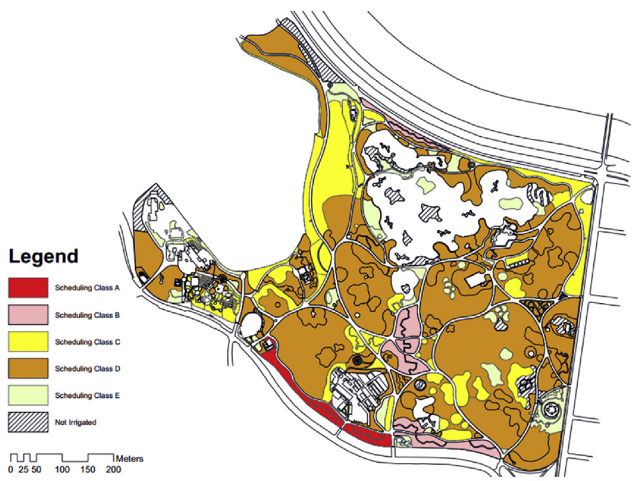


Fig. 12. Summary of microclimate mapping of 18 locations across Melbourne Gardens. Data from Lamb et al. (2016 and pers. comm.).



Scheduling Class	A	B	C	D	E	NI	Totals (m^2)
Total %	3%	3%	21%	60%	8%	5%	
Garden (m^2)	8,238	9,138	36,924	56,811	14,469	13,310	138,890
Lawn (m^2)	-	-	19,743	109,683	6,609	948	136,983
							275,873

Fig. 13. Irrigation scheduling classes for Melbourne Gardens.

3. Concluding remarks

With the Landscape Succession Strategy completed, and its implementation commenced, the Royal Botanic Gardens Victoria is armed and ready to respond to the impending changes to Melbourne's climate. We are confident we will succeed in retaining all the qualities of the landscape and diversity of the collections that give our Melbourne Gardens its much-celebrated cultural and scientific significance. We do know that more research is needed: to find the tolerance envelope for species we want to grow for cultural, scientific and conservation reasons; to source and/or breed genotypes of signature species more able to cope with the predicted climate; and to continue to question each of our accessions as to what its purpose is in this particular botanic garden (which might range from landscape structure, to preservation of a species, to wowing and inspiring visitors), To do all this we need to continue to foster in-house skills and to continue to encourage partnerships with universities and other research organisations. We will draw on our networks of botanic gardens within Victoria, Australia and internationally to share and gather information, and plant material (already we have attracted considerable interest from botanic gardens within Australia and overseas to use our Landscape Success Strategy as a blueprint for responding to climate change). And we need to keep up with advances in science and technology to provide essentials such as reliable irrigation water (it may even be that through innovation we can provide more water, or reduce temperatures locally, and mitigate some of the effects of climate change).

If we succeed in our mission, the visiting public will continue to enjoy one of the world's great botanic garden landscapes and Royal Botanic Gardens Victoria will continue to demonstrate (as we state in our Vision) that *life is sustained and enriched by plants*.

Acknowledgements

We thank many of our colleagues at the Royal Botanic Gardens Victoria for their contributions to the *Landscape Succession Strategy*, and therefore to this paper. We also thank Shanghai Chenshan Botanical Garden and the International Association of Botanic Gardens for hosting the International Symposium on Plant Conservation, and for the invitation and support to present this paper at that meeting.

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