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Assessment of the climate change risk to the living plant collections in the Melbourne Gardens, Royal Botanic Gardens Victoria

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Executive Summary

Climate change is likely to have a significant effect on many species in the living collection at the Melbourne Gardens, Royal Botanic Gardens Victoria. A key aim of the Landscape Succession Strategy for the Melbourne Gardens is to adapt the composition of landscape plantings to a more sustainable collection by incorporating projected environmental change (particularly climate change) into future works. This report describes the results of a project exploring the vulnerability of species in the living collection of the Melbourne Gardens to different climate change scenarios.

The climate risk of the Melbourne Gardens living collection was assessed by comparing the temperature of locations where each species naturally occur and are known to be cultivated, with several temperature projections for Melbourne's climate future. These temperature 'envelopes' for each species were compared with projected climates under current temperatures, and moderate and extreme climate change scenarios for Melbourne to identify the vulnerability of the Melbourne Gardens living collection to current and projected future temperatures.

A total of 8,007 taxa (including 1,273 tree taxa) are currently in the Melbourne Gardens collection. Of this total, 6,103 taxa (comprising 4,660 distinct species) were able to be assessed, including 1,110 tree taxa (961 distinct species). Two climate scenarios were used in this study based on standard, publically available datasets. Under the moderate climate scenario, where mean annual temperatures are forecast to increase by 1.7 °C by 2050 (assuming emissions stabilisation), 15% of tree taxa and 20% of other taxa are considered to be at high risk. Under the extreme climate future where temperatures are forecast to increase by 3.0 °C by 2070 (assuming 'business as usual' emissions), 20% of tree taxa and 26% of other taxa are considered to be at high risk.

Within the Melbourne Gardens mapping grid overlay, changes in the intensity and location of areas at risk were identified. Few grid cells in the Gardens have high levels of risk under the current climate scenario, concentrated in areas such as the New Zealand Collection. One hundred and two grid cells (10,200 m^2 or 3.7% of the living landscape area of 27.7 Ha[1]) have plants with an average risk rating equivalent to a red flag in the moderate climate scenario by 2050. Under the extreme climate scenario by 2070, 173 grid cells (17,300 m^2 or 6.2% of the living landscape area) are predicted to be at high risk from increases in temperature. The risk to tree species shows a similar trend with relatively few trees considered at risk under the current climate scenario (8% of taxa are red flagged). This increases to 15% of tree taxa under the moderate climate scenario of 2050, and 20% under the extreme climate scenario of 2070.

The methods used in this research allow a large number of species to be assessed using very large datasets therefore some caution must be used when interpreting this data. There are likely to be some particular species that respond to future climates differently than predicted using this approach, and the data presented here should be combined with physiological data where available to better understand how particular species are responding to increasing temperatures and water

[1] Living landscape area comprises of garden beds and lawns only. Total area of RBGV is 38.6 Ha.

stress. Also, not all individuals of a particular taxon will be equally at risk. Individual species that have access to favourable conditions may be at less risk than those in difficult sites.

This research demonstrates that many of the current taxa in the Melbourne Gardens living collection are likely to be at risk to further environmental change. The risk to existing taxa can be used to inform management at the Gardens in several ways including:

1) As a priority, change species selection (particularly for long lived species) to favour species at less risk. New species selection can be informed by climate risk ratings, and while the risk of current species to future environments seems dramatic, there are hundreds of possible new species that are potentially suitable for planting in Melbourne.

2) Ameliorate conditions for species at risk that are of high value and choose best locations for new plantings of species at risk i.e. identify suitable microclimates, availability of irrigation. While these species may become less reliable e.g. becoming more susceptible to pests and diseases, with increasing temperatures, they may still be suitable in some places with appropriate management e.g. irrigation, mulching, improved soil conditions, etc.

3) Royal Botanic Gardens Victoria (RBGV) has an opportunity to facilitate plant information exchange – both within Victorian botanic gardens, nationally through Botanic Gardens Australia and New Zealand (BGANZ), and internationally with Botanic Gardens Conservation International (BGCI) so that climatic data for living collections is available to botanic gardens worldwide.

Project background

The Royal Botanic Gardens Victoria (RBGV) has successfully launched their Landscape Succession Strategy 2016 – 2036 (LSS). A key aim of the strategy is to adapt the composition of landscape plantings in Melbourne Gardens to a more sustainable and resilient collection by incorporating projected environmental change (particularly climate change) into future works, whilst also maintaining the 'character' of the Gardens for future generations. The LSS contains explicit targets, e.g. by 2036, 75% of taxa are suitable for the projected climate of 2090. Empirical evidence on the climatic suitability of both current species in the Gardens and potential future species is needed to achieve these targets.

Work is required to identify both existing and new species that are likely to survive and grow well in the environmental conditions predicted for Melbourne's future. However, survival and growth cannot be the only considerations. Focussing on these outcomes alone could lead to perverse outcomes. For example, there is increased risk of invasive weeds, pests and disease that need to be considered when selecting new taxa, however this is not within the scope of this project. *Maladaptation* occurs when adaptation strategies reinforce the effects of the process being adapted (Kendal and Mcdonnell, 2014). For example, replacing broad-leaf deciduous species with species with narrower leaves could affect the provision of key services such as shade and the heritage character of the Gardens.

These problems are common to botanic gardens in Australia and around the world. This project provides an opportunity for RBGV to reinforce the value of strategic landscape planning and plant selection in order to maintain viable living assets.

As a key component, trees are typically the longest living assets in the Gardens and considerable lead time is required in planning landscape succession to provide the benefits of maturity. Therefore, a climate risk assessment has been first prioritised for the 1,273 tree[2] taxa that are currently growing in the Melbourne Gardens, then secondly for the whole collection of 8,007 taxa curated across the living plant collections. The purpose of this project includes:

1) Identifying the level of climate change risk of a range of existing species in the Melbourne Gardens where adequate climatic and distribution data exists.
2) Identifying more likely better adapted taxa to inform future species selection and landscape development.

Combined with tools such as Useful Life Expectancy (ULE) assessments, this information will also be used to inform arboriculture management at the Gardens.

[2] Includes some arborescent, non-woody vegetation e.g. *Cordyline* spp. and tree ferns.

Detailed methodology

The climate vulnerability of the Melbourne Gardens living collection was assessed by comparing the temperature of locations where species naturally occur and are known to be cultivated, with several temperature projections for Melbourne's climate future.

Melbourne Garden's current taxa list

Analysis was conducted at the species level. A total of 8,007 taxa (including 1,273 tree taxa) are currently in the Melbourne Gardens collection. Of these, 1,110 tree taxa (comprising 961 distinct species) and 6,103 other taxa (comprising 4,660 distinct species) were able to be assessed; refer to Appendix 2 for the most common species in the Melbourne Gardens. Tree data is available with GPS coordinates for each tree (Figure 1), while the location of plants in the general collection is referenced to a 10 X 10 metre grid overlaying the Gardens (Figure 2).

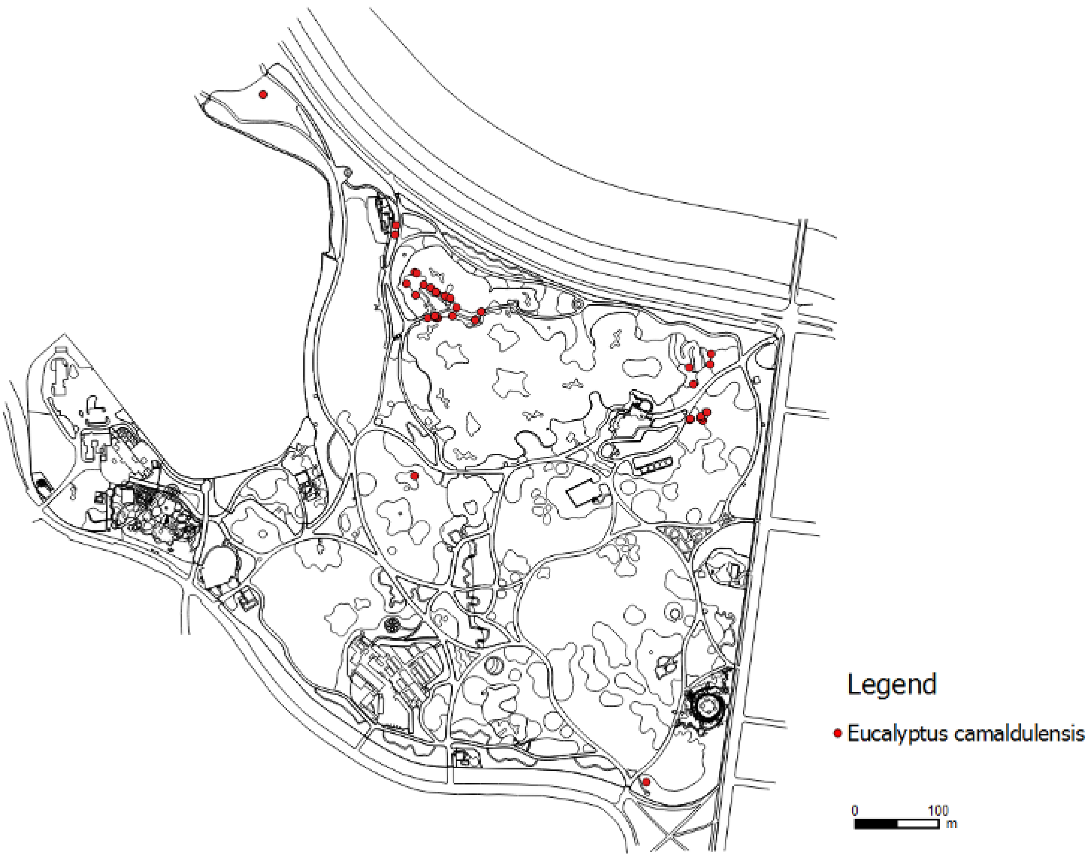

Figure 1 – Point locations of *Eucalyptus camaldulensis* in the Melbourne Gardens.

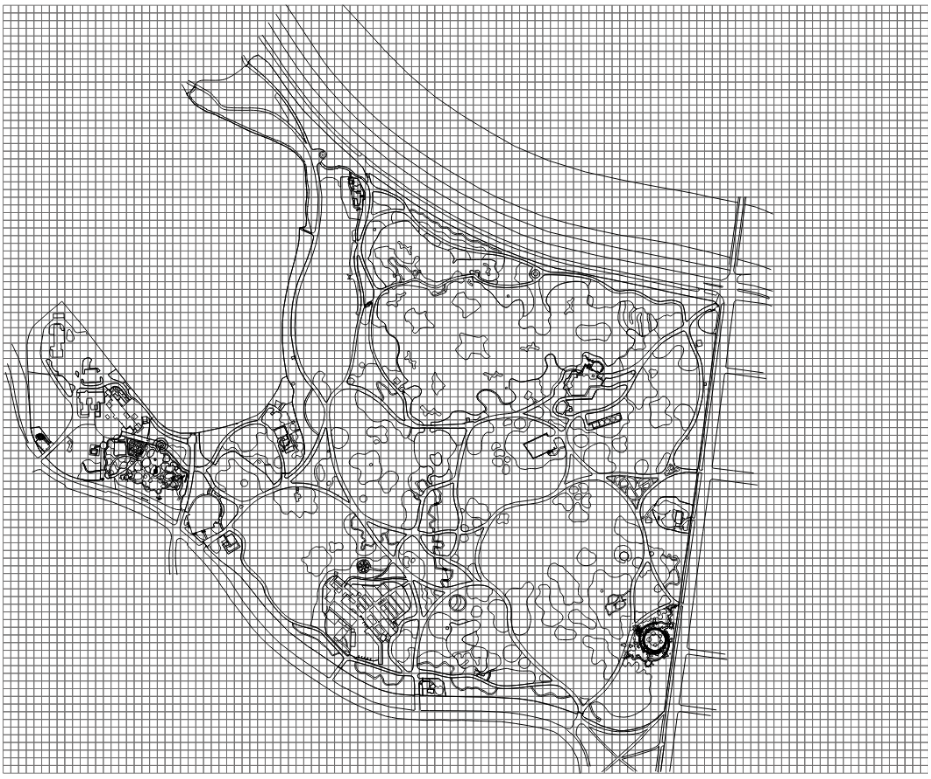

Figure 2 – Grid overlay of the Melbourne Gardens.

The Melbourne Gardens climate

Climate data was recorded at the Melbourne Regional Office weather station in La Trobe Street from 1850 to 2014, and at Olympic Park since 2015. Over this period, the mean annual temperature has varied from 13.9 °C to 17.2 °C, and annual rainfall has varied from 332 to 968 mm. The station at La Trobe Street is affected by surrounding buildings and probably slightly overestimates the temperatures experienced in the Melbourne Gardens.

The historic mean annual temperature before 1950 was approximately 14.8 °C (refer to Appendix 3). Since 1950, this has steadily increased and the average in the last 20 years (1995 - 2014) has been 16.3 °C. This increase has been more pronounced in minimum (i.e. overnight) temperatures, although increases in daytime temperatures have also been observed. There are some indications that extreme maximum temperatures are also increasing. The mean annual rainfall around the Melbourne Gardens region is 650 mm and while there is much more uncertainty in trends (visible in the large scatter of points on the graph, Appendix 3), rainfall over the last 20 years has averaged 564 mm/year, and during the drought of 2002 – 2009, rainfall averaged 488 mm/year. While some of these changes are likely due to human induced global warming (via CO_2 emissions), the magnitude of these changes has been exacerbated by other factors such as the Urban Heat Island effect.

Climate change projections for Melbourne

A range of different climate change models have been developed by a range of scientific organisations around the world. Best practice combines data from many of these different models to determine the probability of the direction and size of change for particular climate variables. Different emission scenarios are modelled based on assumptions about whether we will be able to limit global emissions (Representative Concentration Pathway (RCP) 4.5 scenario) or allow emissions to continue to increase (RCP 8.5 scenario). Both the RCP 4.5 (refer to Appendix 4 a & c) and RCP 8.5 (Appendix 4 b & d) multi-model averages suggest that about 0.5 °C of the temperature increases observed in Melbourne by 2015 can be attributed to climate change. These models predict temperature increases of respectively 1.7 °C (for RCP 4.5 by 2050) and 3 °C (RCP 8.5 by 2070, increasing Melbourne's mean annual temperature to 18.0 °C and 19.3 °C respectively using mean (50^{th}) percentile model predictions including urban heat.

Rainfall projections from these climate models are uncertain although the extreme climate change model predicts a slight (less than 10%) decline in rainfall by 2070. While this is not as large or as certain as changes in temperature, declines in rainfall interact with increasing temperatures to increase water demands. For example, a 10% reduction in rainfall is significant when combined with increases in evapotranspiration and risk of more extreme low rainfall years, which could increase additional water demand by 21% (RBGV, 2016).

Identifying climate parameters limiting global tree distributions

BIOCLIM is a set of 19 climate envelope variables that relate to the distribution of plant species in natural systems (Booth *et al.,* 2014). Using these variables is a well established method for understanding the response of trees to climate change (McKenney *et al.,* 2007). For all relevant climate variables, averages (50^{th} percentile) and limits (2.5^{th} and 97.5^{th} percentiles) were calculated for natural distributions and cultivated distributions.

Annual temperature is considered one of the most important predictors of plants, and an important determinant of the distribution of urban tree taxa globally (Kendal *et al*., 2012). Mean annual temperature (BIOCLIM 1) will be used as the primary variable for assessing risk to climate change, and has been demonstrated to be a strong predictor of the temperatures where species are cultivated (Kendal *et al.*, in prep). For all species assessed, extreme temperature data were included in the analysis to inform decision making. Mean minimum temperature in °C of coldest quarter (BIOCLIM 11) and mean maximum temperature of warmest month (BIOCLIM 5) were determined to be the most useful extreme variables informing distribution in cultivation.

Precipitation is a weaker predictor of climatic suitability (Kendal, *et al*., in prep), and precipitation deficit is more amenable to compensation through irrigation. Nonetheless, precipitation data still provides some useful evidence to include in landscape planning. Annual precipitation (BIOCLIM 12) and precipitation of the driest quarter (BIOCLIM 17) were included in the analysis.

Examination of raw BIOCLIM data confirms Melbourne's historic climate, with point data for Melbourne's location (longitude = 144.9631; latitude = -37.8136) having a BIOCLIM 1 (mean annual temperature) value of 148 (14.8 °C) and a BIOCLIM 12 (mean annual rainfall) value of 675 mm.

Benchmarks for Melbourne Gardens future temperature

Benchmarks for the future temperature of the Melbourne Gardens were derived from 1986 - 2015 climate averages and combined with climate change projections. As the BIOCLIM model deliberately excludes non-climate change related influences such as urban heat, current mean and extreme annual temperature values were calculated based on averages from Bureau of Meterology records over the last 20 years (1995 - 2014) at the Melbourne Regional Office weather station (Table 1) to include current and future urban heat island effects in the analysis.

These current values, combined with climate change predictions from modelled data available from Worldclim (www.worldclim.org) were then used to predict future mean annual temperature values for the Melbourne Gardens. Worldclim makes available global, spatially explicit datasets for the RCP 4.5 and RCP 8.5 scenarios in both 2050 and 2070. In 2050, the moderate climate future under the RCP 4.5 emissions scenario (assuming emissions stabilisation) forecasts a 1.7 °C increase in temperature. The 2070 extreme climate future under the RCP 8.5 emission scenario (assuming 'business as usual' emissions) forecasts a 3.0 °C increase in temperature. These climate scenarios were chosen because high quality data is readily available, and they provide a useful guide to likely future temperatures. Current CO_2 emissions are tracking at slightly higher the RCP 8.5 scenario, so these should be considered reasonably conservative forecasts based on current data and policy settings. Worldclim projections exclude urban heat, and a conservative figure of 1.5 °C was added to the raw Worldclim projections, giving total projected increases in mean annual temperature of 3.2 °C in the moderate scenario and 4.5 °C in the extreme scenario.

Table 1 – Climate averages for Melbourne for historic, current, and projected values for moderate and extreme climate scenarios.

Variable	Mean annual temp.	Mean max of hottest month	Mean min of coldest month	Annual precip.	Precip. of the driest quarter
Historic values (pre 1950)	14.8 °C	26.2 °C	5.7 °C	675 mm/year	137 mm/year
Current values (1995 - 2014)	16.3 °C	27.2 °C	7.5 °C	612 mm/year	133 mm/year
Moderate climate future (RCP4.5 at 2050)	18.0 °C	28.9 °C	8.8 °C	687 mm/year	141 mm/year
Extreme climate future (RCP8.5 at 2070)	19.3 °C	30.8 °C	10.3 °C	613 mm/year	124 mm/year

The temperature envelopes of species

The global distribution of species was determined using data from The Global Biodiversity Information Facility (GBIF; www.gbif.org) which has 650 million occurrence records from over 1.5 million species globally. The GBIF database is a superset of the datasets from the Atlas of Living Australia. Occurrence records include natural distributions, weed records and some urban floras. A total of 15 million observations of the species of interest were used in the analysis (Appendix 6). A second dataset, cultivated urban plant inventories, was manually collected from over 400 urban plant inventories published in academic papers and government reports (Appendix 6). The location of the city was used to determine the temperature of occurrence of these urban trees. Over 25,000 records were included in this dataset. For the purposes of this research, cultivars were included as species only. Cultivars and selections are an important response to this research, but little data exists on the provenance and climatic suitability as they are not represented in the GBIF database.

Good information coverage was considered to be at least 30 GBIF records or 5 cultivated flora records. Of the 5,797 total species in the Gardens, 4,660 species (80%) matched with the compiled databases, (representing 76% of taxa in the Gardens), with 3,806 species (66%) having good coverage. Of the 1,100 tree species in the Gardens, 961 species (87%) matched the compiled databases with 935 species (85%) having good coverage (Table 2).

Table 2 - Summary of how many taxa and species in the Melbourne Gardens living collection were matched with the complied datasets from the GBIF and cultivated urban plant inventories.

	No. taxa in living collection	Taxa matched with compiled datasets	No. species in living collection	Species matched with compiled datasets	Species with good coverage in compiled datasets
Whole collection	8,007	6,103 (76%)	5,797	4,660 (80%)	3,806 (66%)
Only trees	1,273	1,100 (86%)	1,100	961 (87%)	935 (85%)

The temperature envelopes for each species in the Melbourne Gardens living collection was identified by searching for species point locations in the GBIF database, and in urban plant inventory records (global cultivated plant inventory). The matching BIOCLIM variables for the GPS location where the species had been recorded were then extracted. The distribution of each of the temperature variables were then be examined (see Figures 3 & 4 for the temperature envelope for *Eucalyptus leucoxylon*). Where both cultivated flora and GBIF data were available, climate envelopes were combined into a single envelope. Where there were few records (<30 GBIF records and <5 cultivated flora records), it is likely that these records do not adequately represent the suitable temperature envelopes (854 species in the living collection, including 26 tree species had inadequate coverage). These species were marked as having limited data in the supplied species assessments.

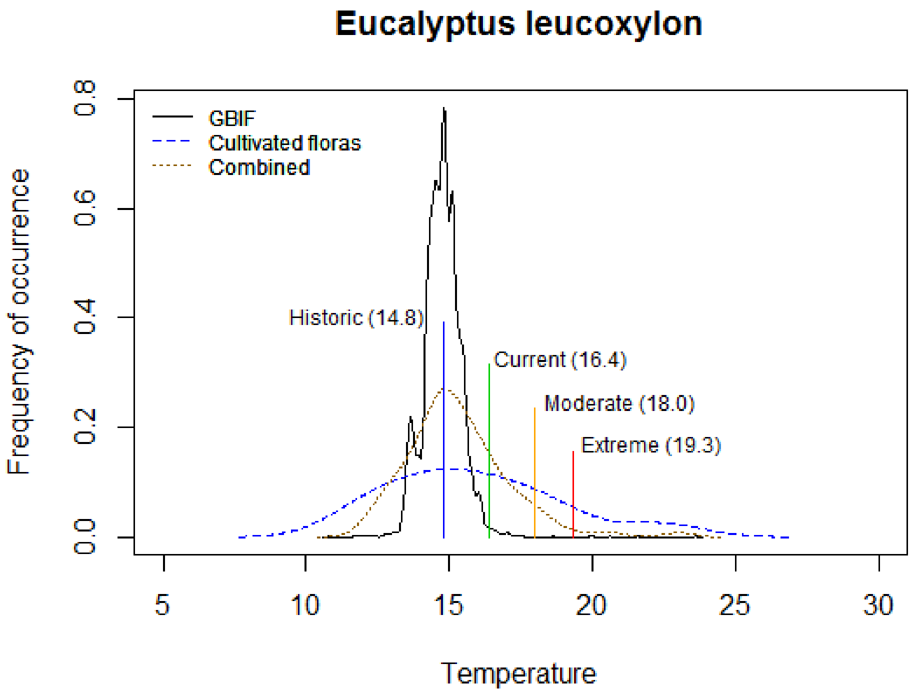

Figure 3 - Mean annual temperature of places with point records for *Eucalyptus leucoxylon.* Melbourne's historic mean annual temperature (blue), current mean annual temperature (green), predicted mean annual temperature with moderate climate change (orange) and extreme climate change (red) are shown as vertical lines.

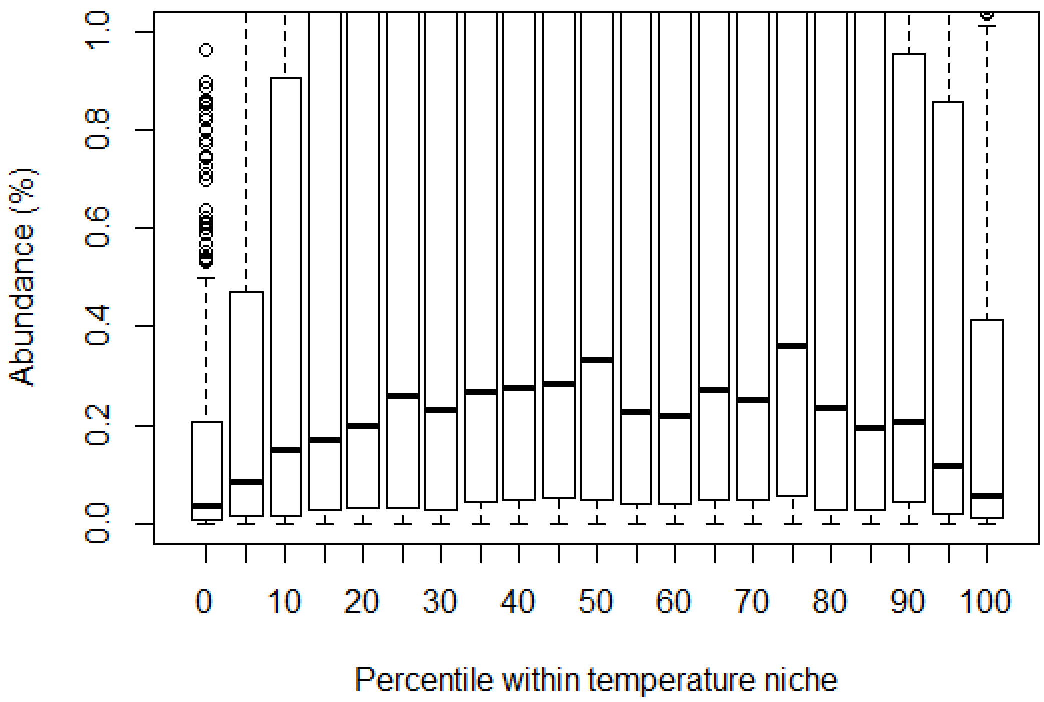

Figure 4 – Abundance against location within temperature niche for all species within urban tree inventories, showing that abundance declines near the limits of the niche (where percentile <20 or >80).

One issue noted with the temperature dataset was some species naturally have relatively narrow temperature envelopes and are not widely planted globally. For example, there are many hundreds of species of Eucalyptus that naturally occur across a range of only 2 – 3 °C. It is likely that these species could be planted more widely in cities, as cultivation overcomes some of the limiting factors (particularly barriers to germination). For narrow range species, the temperature envelope was widened to average values. Table 3 shows the average envelopes relative to mean distributions of all species. As the 2.5th and 97.5th percentile were used in calculating the purple and red flags, this means that temperature envelopes were adjusted to be a minimum of approximately +/- 5 °C around the mean, which is consistent with Booth (Booth, 2015).

Table 3 – The average temperature envelopes relative to the mean distributions for all species.

Percentile	0	1	2.5	5	10	15	20	50	80	85	90	95	97.5	99	100
GBIF	-8.6	-5.8	-4.7	-3.9	-3.0	-2.4	-1.9	0.0	1.9	2.4	3.0	3.9	4.7	5.5	7.8
Inventory	-4.3	-4.1	-3.8	-3.5	-2.9	-2.6	-2.2	0.0	3.4	4.1	4.9	5.7	6.2	6.6	6.8

Determining a 'temperature window' guidance system for identifying risk in future climate scenarios

The location of the Melbourne Gardens within the temperature envelope for each species was coded into 'temperature windows' indicating the risk for each climate change scenario. Temperature windows based on the following climate varibles were produced for the climate scenarios:

- Current climate:
  - mean annual temperature 16.3 °C
- Moderate climate future by 2050 (35 year timeframe) assuming:
  - a 1.7 °C increase in mean annual temperature to 18.0 °C
- Extreme climate by 2070 (a 55 year timeframe) assuming:
  - a 3.0 °C increase in mean annual temperature to 19.3 °C

Precipitation data and data for other bioclimatic variables was also provided for each scenario, although this was not included in the vulnerability calculations. Vulnerability was analysed using the calculated temperature limits of the known distribution for each species, and examining the edges of the temperature distribution (Figure 5). Where Melbourne's current or future temperature is close to the bottom of the distribution, Melbourne is potentially too cold for that species (Figure 4). The degree of risk increases in proporation to how close Melbourne is to the temperature limits of that species. For example, where Melbourne's temperature is above the 97.5th percentile of a species known temperature niche, that species is considered most at risk due to heat. Risk then decreases away from these limits in 5th percentile brackets (95-90, 90-85, 85-80; Table 4). Similarly, where Melbourne's temperature is below the 2.5th percentile of a species known temperature niche, that species is considered most at risk from cold. Risk then decreases in 5th percentile brackets (5-10, 10-15, 15-20); Table 4). Where the Melbourne temperature falls between the 20th and 80th percentile, the species is considered unlikely to be vulnerable due to heat or cold.

For each climate scenario, all species in the Melbourne Gardens that had at least 3 records in our cultivated flora database, or 5 records in the GBIF database, were analysed. Based on the risk assessment, each species was assigned a colour representing temperature vulnerability (Table 5).

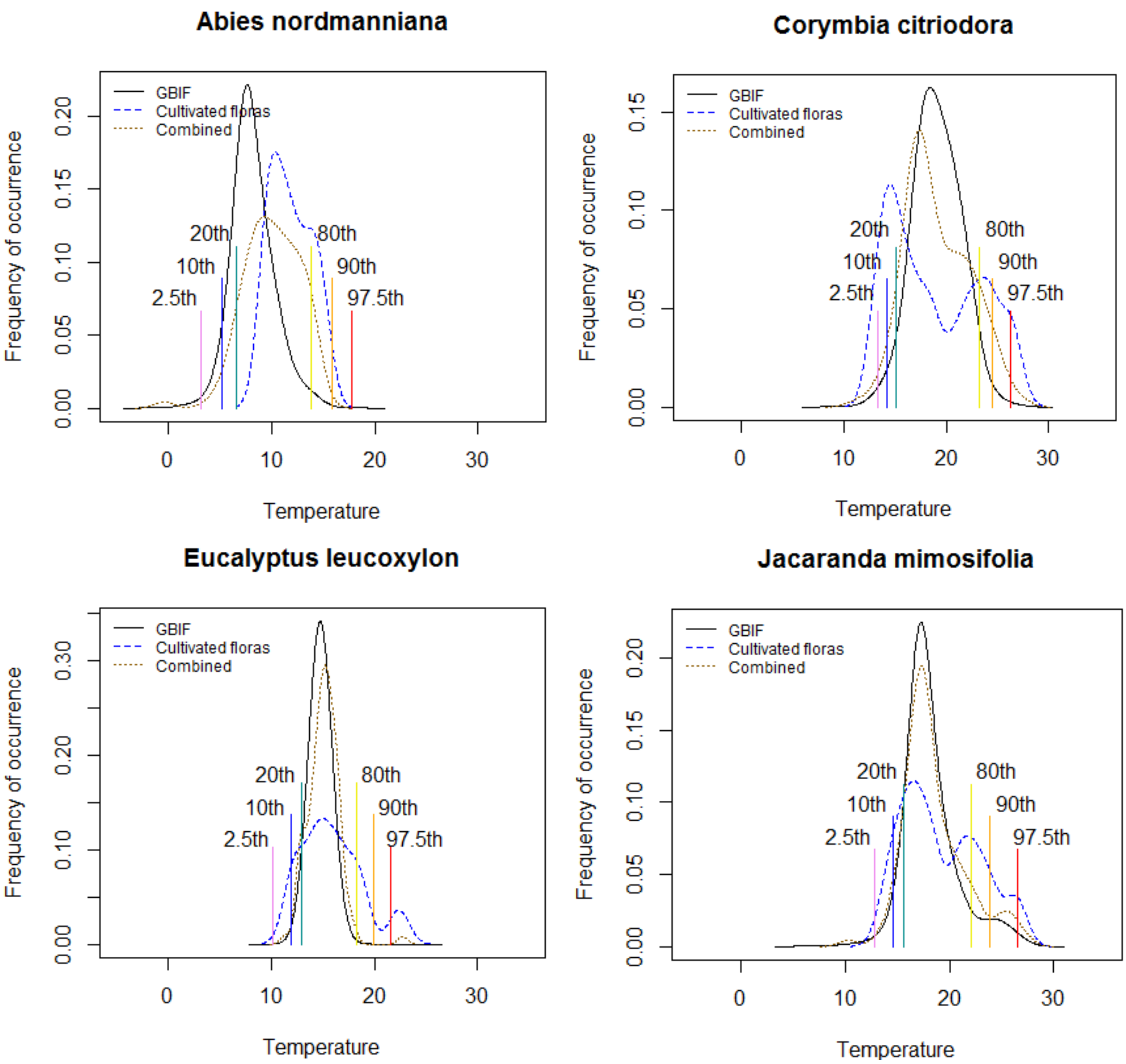

Figure 5 – the key temperature parameters used in determing vulnerability for *Abies nordmanniana, Corymbia citriodora, Eucalyptus leucoxylon* and *Jacaranda mimosifolia*. Coloured lines indicate temperature thresholds.

Table 4 – Heat and cold risk scale ratings, from 7 (high risk) to 0 (low risk).

Heat vulnerability rating	7	6	5	4	3	2	1	0
Percentile	100	> 99	< 99-97.5	< 97.5-95	< 95-90	< 90-85	< 85-80	< 80
Cold vulnerability rating	7	6	5	4	3	2	1	0
Percentile	0	< 1	> 1-2.5	> 2.5-5	> 5-10	> 10-15	> 15-20	>20

Table 5 – Temperature risk colour coding scheme.

Rating	Metric	Example in current climate	Description
Green	Melbourne's temperature is within the middle 80% of all the climates at all locations where the species occurs (i.e. Melbourne's temperature is between the 20th percentile and the 80th percentile)	*Abelia chinensis*	Species is not considered vulnerable in this temperature scenario
Yellow	Melbourne is warmer than 80% of locations where the species occurs (i.e. Melbourne's temperature is between the 80th percentile and 90th percentile)	*Forsythia viridissima*	The species is slightly vulnerable in this temperature scenario
Orange	Melbourne is warmer than 90% of the locations where this species is found (i.e. Melbourne's temperature is between the 90th percentile and 97.5th percentile)	*Furcraea parmentieri*	The species is moderately vulnerable in this temperature scenario
Red	Melbourne is warmer than 97.5% of the locations where this species is found (i.e. Melbourne temperaure is greater than the 97.5th percentile)	*Acacia alpina*	The species is very vulnerable in this temperature scenario
Aqua	Melbourne is colder than 80 - 90% of locations where this species is found. (i.e. Melbourne temperature is between the 20th percentile and 10th percentile)	*Maranta leuconeura*	The species is slightly vulnerable in this temperature scenario
Blue	Melbourne is colder than 90% of the locations where this species is found (i.e. Melbourne's temperature is between the 10th percentile and 2.5th percentile)	*Gardenia volkensii*	The species is moderately vulnerable in this temperature scenario
Purple	Melbourne is colder than 97.5% of the locations where this species is found (i.e. Melbourne's temperature is lower than the 2.5th percentile)	*Ficus opposita*	The species is very vulnerable in this temperature scenario

Results

Of the 6,103 taxa in the Melbourne Gardens able to be analysed, a large proportion are somewhat at risk to increasing temperatures from climate change and urban heat (Table 6). Of the 6,103 taxa in the Melbourne Gardens, 20% of taxa (15% of tree taxa) largely occur outside of Melbourne's moderate future climate (red flagged). A total of 26% of taxa (20% of trees) are orange or red flagged in the extreme scenario.

Visualising the change in risk over time (Figures 6 – 11), changes in intensity and location of risk areas can be seen. Within the Melbourne Gardens grids, 43 grid cells (4,300 m^2 or 1.6% of the living landscape area (27.7 Ha)[3]) are considered at high risk (average plant risk is red flagged) from heat under the current climate scenario (Figure 6), concentrated in areas such as the New Zealand Collection. Under a moderate climate scenario by 2050, the number of grid cells at high risk from heat increases to 102 (10,200 m^2 or 3.7% of living landscape) (Figure 7). This risk intensifies further under the extreme climate scenario by 2070, where 173 grid cells (17,300 m^2 or 6.2% of living landscape) are predicted to be at high risk from increases in temperature (Figure 8).

The risk to trees shows a similar trend. There are 185 trees considered at high risk from heat under the current climate scenario (Figure 9). This increases to 409 trees under the moderate climate scenario (Figure 10), and by 2070 under the extreme climate scenario, 521 trees are considered at high risk from heat (Figure 11).

Risk to the cold was not considered in detail as this will decline with increasing temperatures, and many of the species at risk to cold are housed in glasshouses. For example, 41% of taxa currently considered most at risk to cold (purple flagged) are located in glasshouses.

[3] Living landscape area comprises of garden beds and lawns only. Total area of RBGV is 38.6 Ha.

Table 6 – Proportion of Melbourne Gardens current taxa at risk to future temperatures.

		Number of taxa										Percentages						
		purple	blue	aqua	green	yellow	orange	red	Not rated	Grand Total	Assessed	purple	blue	aqua	green	yellow	orange	red
Current climate	All Plants	319	421	366	3172	513	583	729	1904	8007	6103	5%	7%	6%	52%	8%	10%	12%
	Trees	50	104	76	590	96	110	84	163	1273	1110	5%	9%	7%	53%	9%	10%	8%
Moderate climate future	All Plants	161	236	242	2557	880	782	1245	1904	8007	6103	3%	4%	4%	42%	14%	13%	20%
	Trees	22	39	54	511	189	125	170	163	1273	1110	2%	4%	5%	46%	17%	11%	15%
Extreme climate future	All Plants	105	175	198	2021	1000	1046	1558	1904	8007	6103	2%	3%	3%	33%	16%	17%	26%
	Trees	14	24	40	441	187	185	219	163	1273	1110	1%	2%	4%	40%	17%	17%	20%

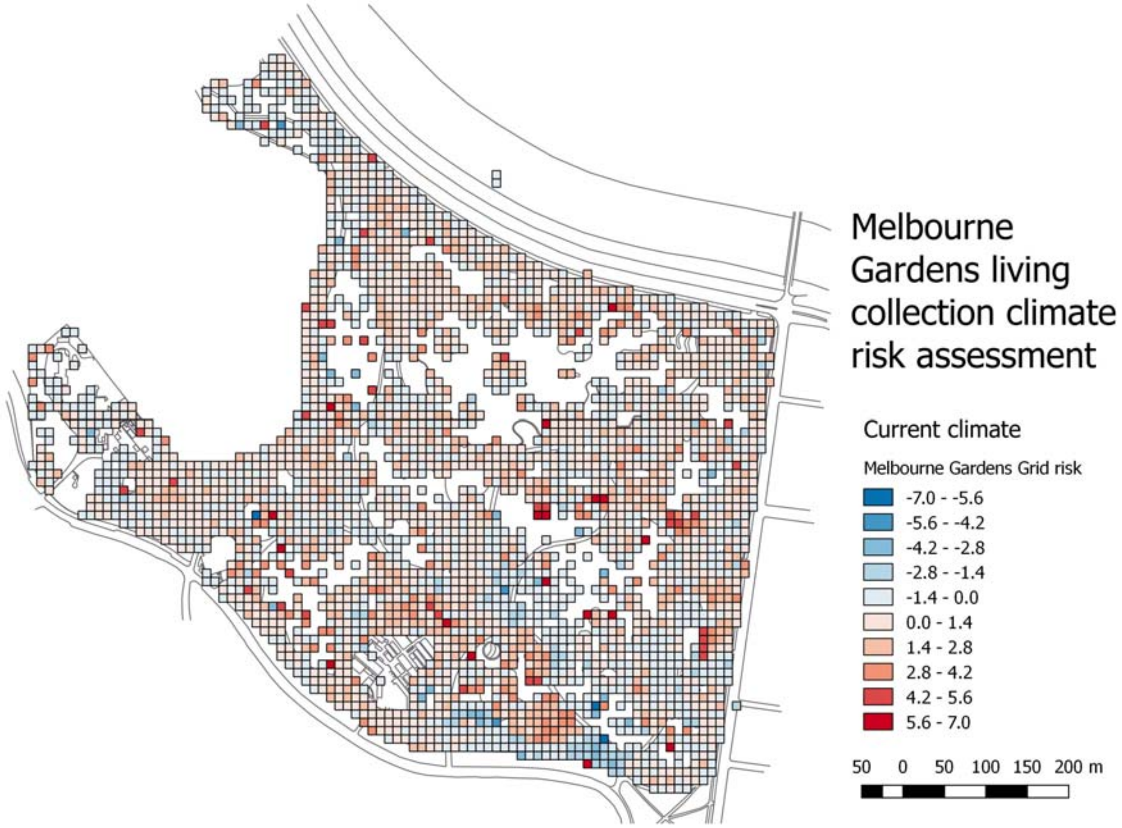

Figure 6 – Risk to grid areas within the Melbourne Gardens based on all species under the current climate scenario.

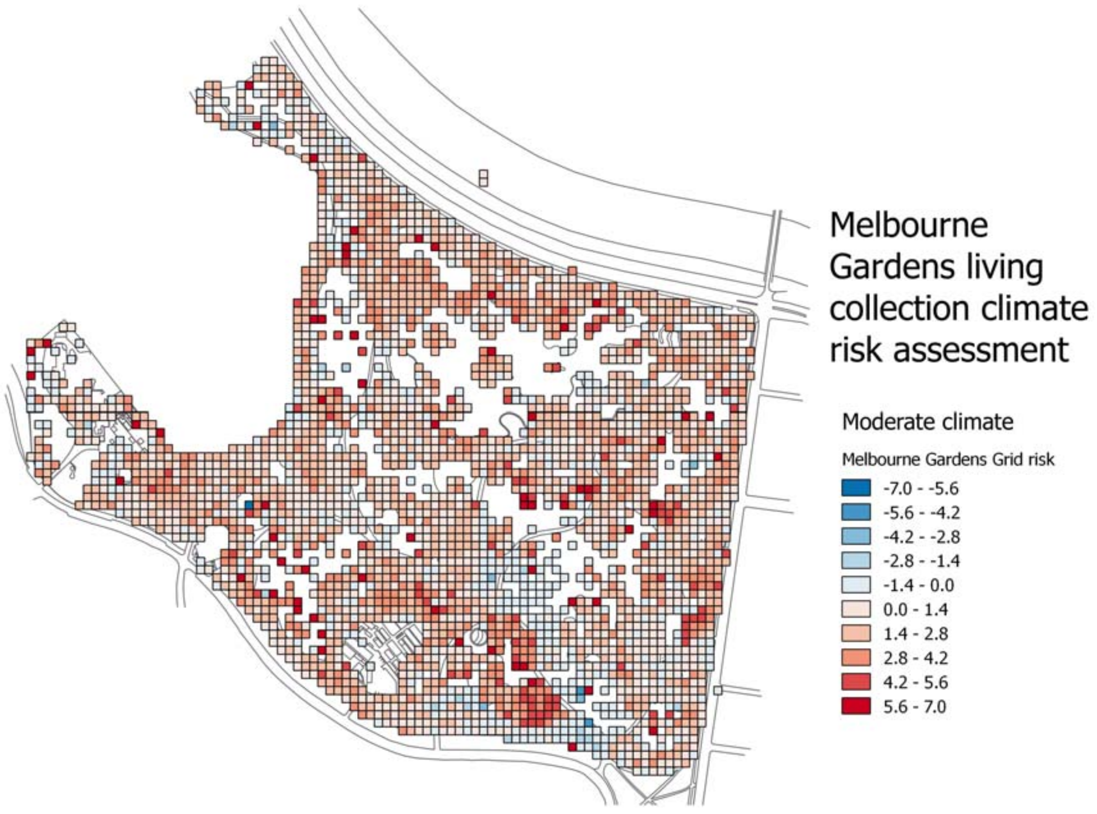

Figure 7 – Risk to grid areas within the Melbourne Gardens based on all species under the moderate climate scenario.

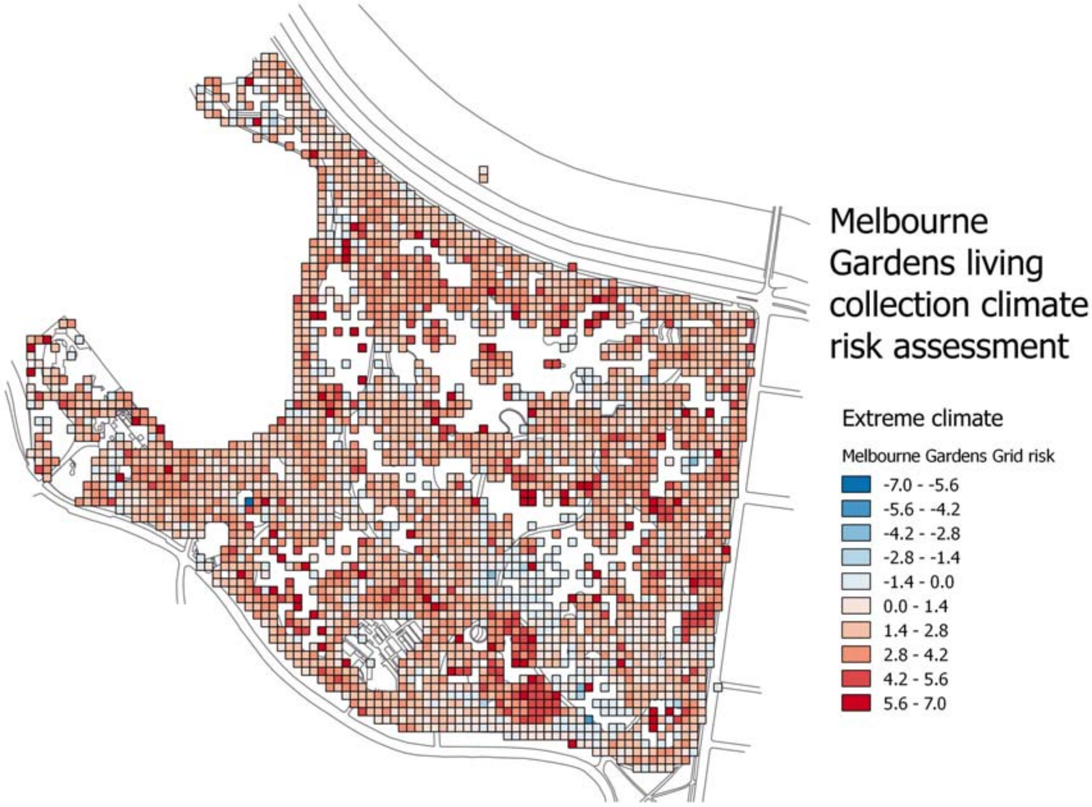

Figure 8 – Risk to grid areas within the Melbourne Gardens based on all species under the extreme climate scenario.

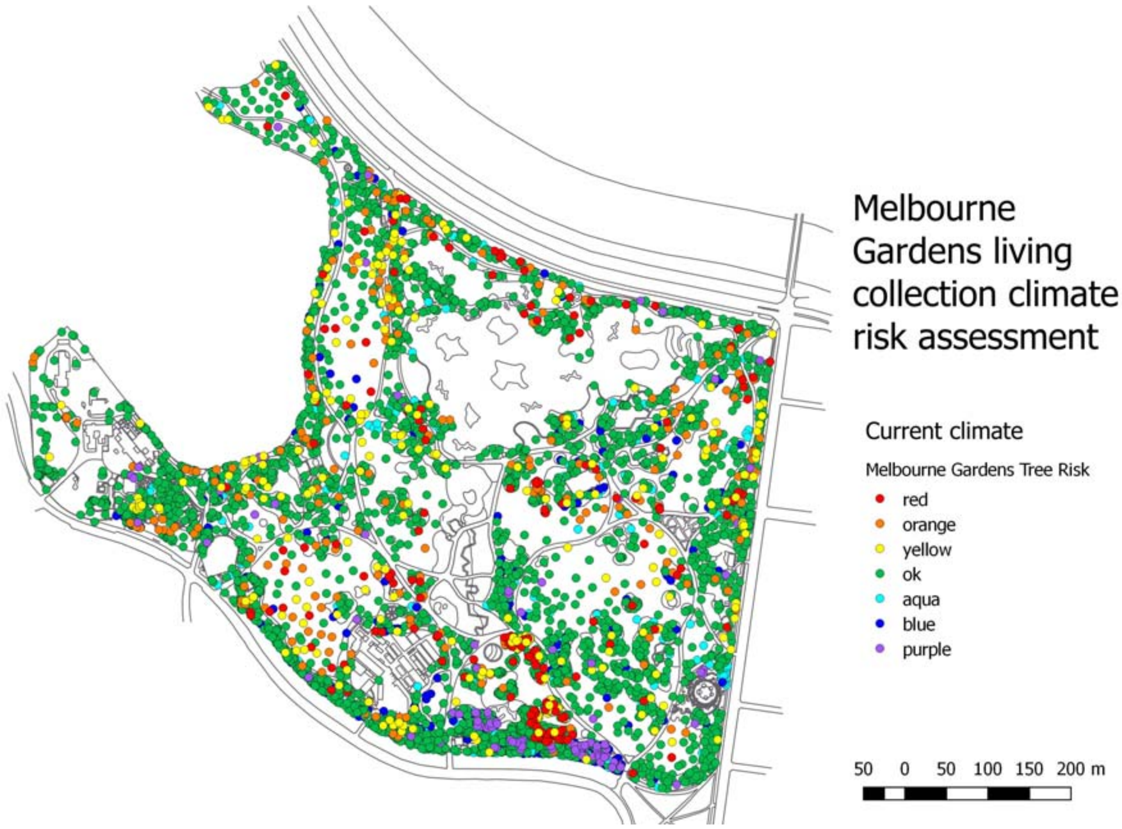

Figure 9 – Risk to trees within the Melbourne Gardens under the current climate scenario.

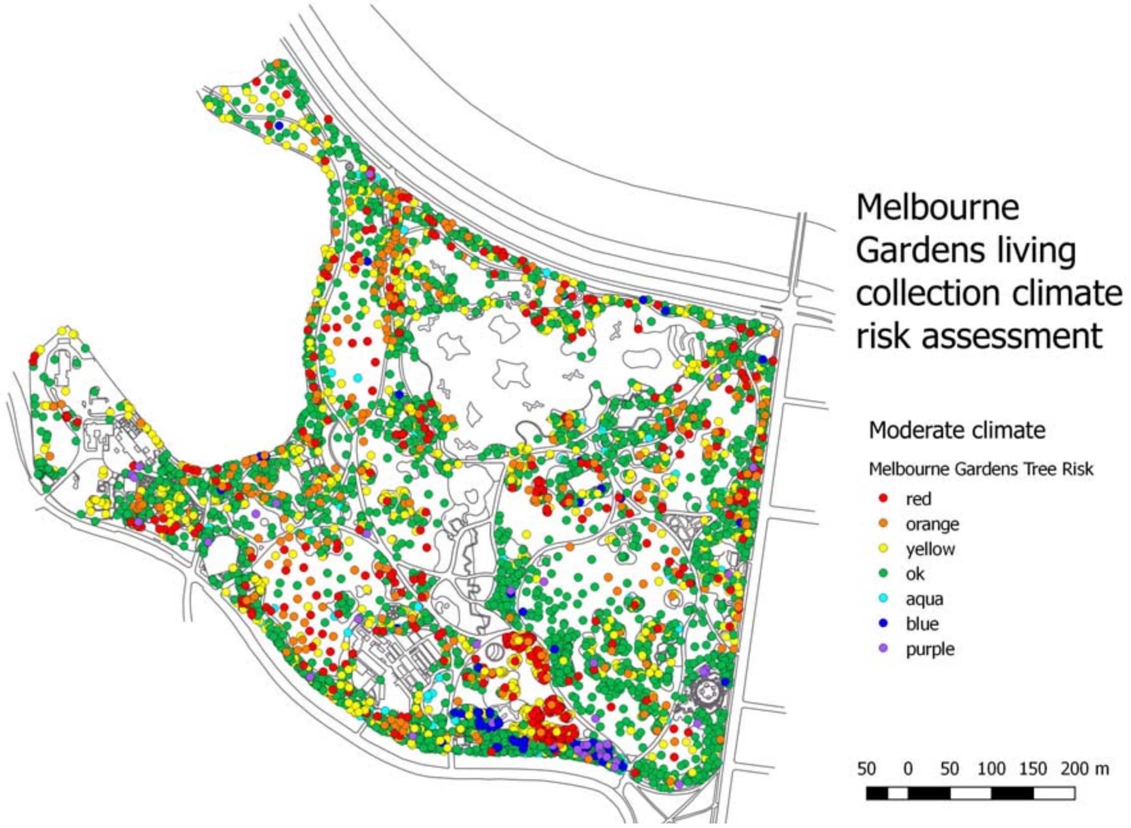

Figure 10 – Risk to trees within the Melbourne Gardens under the moderate climate scenario.

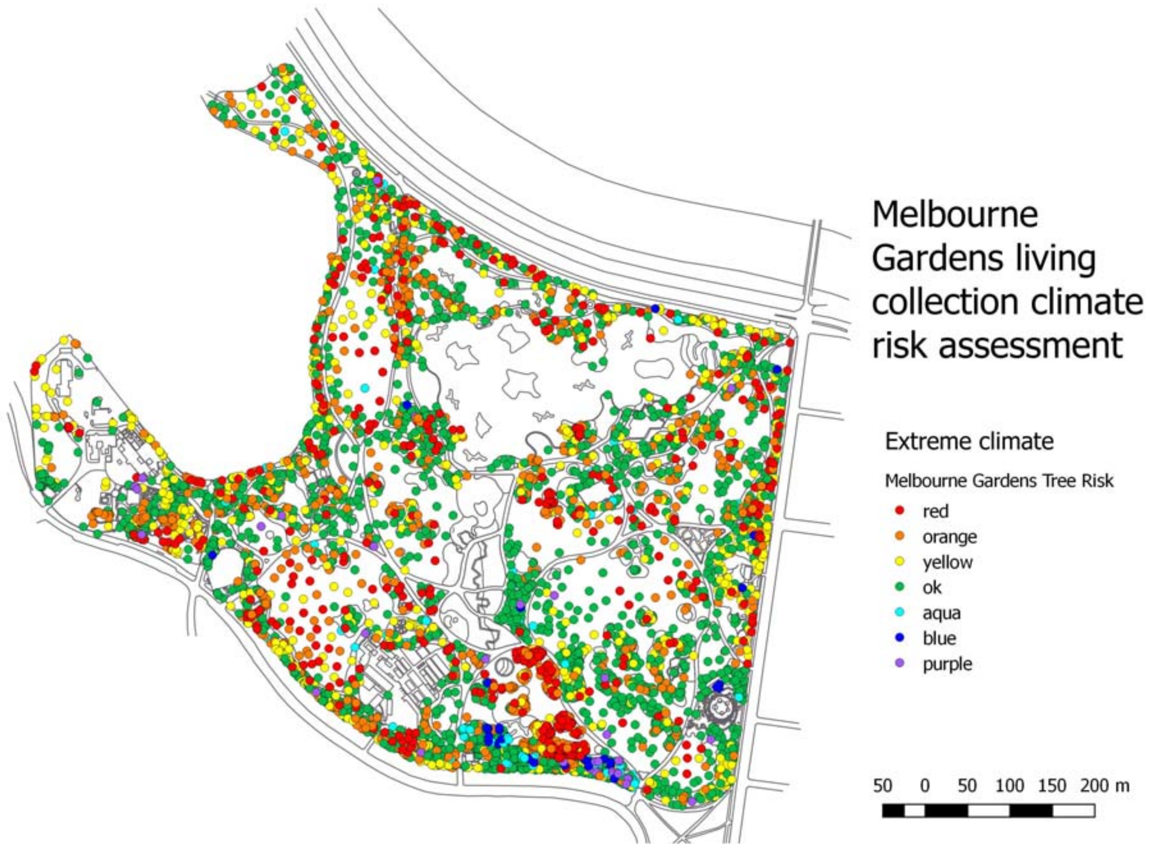

Figure 11 – Risk to trees within the Melbourne Gardens under the extreme climate scenario.

New species

The species occurring in the global inventory database that do not currently occur in the living collection of the Melbourne Gardens were also assessed against risk categories under current and future climates. This assessment shows that there are many hundreds of plant species (mostly trees) that are found in other cities around the world (see separate spreadsheet as provided electronically for a list of species and risk ratings). This includes a wide range of native and exotic species, and different plant forms (deciduous, palms, broad leaf, etc).

Table 7 – Number of new species occurring in different risk categories in different climate scenarios.

	Purple	Blue	Aqua	Green	Yellow	Orange	Red
Current	409	204	115	575	121	154	363
Moderate	267	208	131	488	169	182	496
Extreme	138	221	135	448	147	245	607

Table 8 – A sample of green flagged new species in different climate scenarios.

Moderate	Extreme
Ficus lyrata	*Quercus nigra*
Citrus japonica	*Vitex agnus-castus*
Citrus reticulata	*Ulmus crassifolia*
Corymbia eximia	*Afrocarpus gracilior*
Hakea sericea	*Eucalyptus gomphocephala*
Photinia serratifolia	*Caesalpinia ferrea*
Pinus echinata	*Chitalpa tashkentensis*
Ulmus alata	*Eucalyptus decorticans*
× *Chitalpa tashkentensis*	*Ilex vomitoria*
Acacia prominens	*Eriobotrya deflexa*
Aesculus pavia	*Koelreuteria elegans*
Fraxinus berlandieriana	*Pinus massoniana*
Grevillea hookeriana	*Pittosporum rhombifolium*
Morella cerifera	*Salix humboldtiana*
Prosopis chilensis	*Cercidium floridum*
Quercus texana	*Xanthostemon chrysanthus*
Ricinus communis	*Brahea edulis*
Sophora secundiflora	*Prosopis glandulosa*
Grevillea banksii	*Triadica sebifera*
Acacia salicina	*Ebenopsis ebano*
Angophora hispida	*Markhamia lutea*
Dypsis decaryi	*Ficus lyrata*
Eucalyptus occidentalis	*Citrus japonica*
Tibouchina granulosa	*Citrus reticulata*
Eucalyptus microtheca	*Pinus echinata*

New Plant Assessment Tool

A tool to conduct a risk assessment for current or new species to be planted at the Melbourne Gardens was developed. The tool is an R script that can be used to assess the climate risk of new species for the Melbourne Gardens living collection. The R script is designed for use in RStudio, which is a freely available tool for running R, a statistical programming language. The scripts also require the freely available Dismo and Raster packages to be installed.

Installing the script

The supplied script can be opened directly in R studio. The first line in the script should be changed to set the working directory from which the script is being run.

Running the script

The script loads an excel file (species_to_be_assessed.csv), which contains a list of species to be assessed in the first column of the spreadsheet.

The script will assess the species and write an excel file (species_climate_assessments.csv) containing the results of the assessment. The fields in this spreadsheet are:

- species - the name of the species
- gbif.records – the number of GBIF records found for this species
- current - the traffic light coding under current temperatures
- moderate - the traffic light coding under the RCP4.5 2050 temperature scenario
- extreme- the traffic light coding under the RCP8.5 2070 temperature scenario
- temp.median - the median (50^{th} percentile) of mean annual temperature (MAT) of the occurrence of the species in the GBIF database
- temp.80^{th} - the 80^{th} percentile of MAT of the occurrence of the species (yellow threshold)
- temp.90^{th} - the 90^{th} percentile of MAT of the occurrence of the species (orange threshold)
- temp.97.5^{th} - the 97.5^{th} percentile of MAT of the occurrence of the species (red threshold)
- temp.20^{th} - the 20^{th} percentile of MAT of the occurrence of the species (aqua threshold)
- temp.10^{th} - the 10^{th} percentile of MAT of the occurrence of the species (blue threshold)
- temp.2.5^{th} - the 2.5^{th} percentile of MAT of the occurrence of the species (purple threshold)
- precip.median - the median (50^{th} percentile) of annual precipitation of the occurrence of the species in the GBIF database
- precip.20^{th} - the 20^{th} percentile of annual precipitation of the occurrence of the species
- temp.10^{th} - the 10^{th} percentile of annual precipitation of the occurrence of the species
- temp.2.5^{th} - the 2.5^{th} percentile of annual precipitation of the occurrence of the species

Implications and Recommendations for the Melbourne Gardens

The temperature in Melbourne has changed dramatically in response to increasing urbanisation and will continue to change in response to climate change. This research clearly demonstrates that many of the current species in the Melbourne Gardens living collection are likely to be at risk to increasing temperatures. Identifying the risk to existing species can be used to inform management at the Melbourne Gardens in several ways:

1. Change species selection, particularly for long-lived plants such as trees, to favour species at lower risk. New species selection can be informed by climate risk ratings and additional climate data (e.g. extreme temperatures, precipitation). While there are many new species that will be potentially suitable for future climates, there will be greater uncertainty about the outcomes of management actions. Processes will need to be developed to select and test these species in order to determine their suitability.

2. Ameliorate conditions for species at risk and of high value e.g. irrigation, mulching, improved soil. There are two groups of species particularly vulnerable:

    i. Species from colder climates, such as northern Europe and the north-eastern United States.
    ii. Species with narrow climate envelopes, such as many locally indigenous plants and other native trees (e.g. *Eucalyptus* spp. and *Acacia* spp.)

    Both these groups of plants make very important contributions to the Gardens cultural identity and biodiversity. While these species may become less reliable (e.g. becoming more susceptible to pests and diseases) with increasing temperatures, they may still be suitable in some places with appropriate management e.g. irrigation, mulching, improved soil conditions, etc.

3. Choose best locations for new plantings of species at risk e.g. suitable microclimates, irrigation availability. Records from the Melbourne Gardens suggests that average temperature differences can vary by -0.7 °C to +0.7 °C between sites for warm periods of the year.

4. The risk map of the Gardens can be used to identify areas to target management. This is particularly important for trees that can take a significant amount of time to establish. There will also likely be a need for increased tree removal, pruning, and planting in response to damage, decline, and mortality.

5. The RBGV could take a global leadership role in helping botanic gardens adapt to increasing temperatures. This could be through facilitating plant information exchange – both within Victorian botanic gardens, nationally through Botanic Gardens Australia and New Zealand (BGANZ), and internationally with Botanic Gardens Conservation International (BGCI) so that climatic data for living collections is available to botanic gardens and or urban horticulture worldwide.

The methods used in this research allow a large number of species to be assessed using very large datasets. This allows trends and patterns of risk to be predicted. However, there are likely to be some particular species that respond to future climates differently than predicted using this approach. The information presented here should be combined with detailed information on the physiological response of particular species and cultivars of interest to future climates, using methods such as dendrochronology, infrared imagery or other measures of physiological response of trees to temperature and water stress.

Another important caveat is that not all individuals within species will be equally at risk. Individual plant species that have access to protection from hot northerly winds, adequate irrigation through summer and favourable soil volume and structure will likely be at lower risk than individual species that are in exposed sites, without irrigation, or growing in a small volume of compacted soil. Improving soil conditions and water availability may help reduce the risk to existing plants from temperature increases. Suitable site selection, preparation and maintenance may allow individuals of species at risk to continue to be planted into the future.

Further Research

There are several important research needs that have been identified at the conclusion of this project:

1) How do we develop plant selection methodologies for the Melbourne Gardens?

   This research identified species in the Melbourne Gardens living collection that are at risk under future climate scenarios. We currently have limited knowledge to guide selection of more suitable species against a shifting climate regime. Plant selection approaches need to factor in a better understanding of the botanical and horticultural values, ecosystem services, habitat, and cultural values of the Melbourne Gardens to ensure that the diverse functions of the landscape are met into the future. It is important to continue to refine and test assumptions about plant selection methodology for the Melbourne Gardens as well as gardens globally.

2) How will the changes to the Melbourne Gardens affect its botanical and horticultural value, people and biodiversity?

   A better understanding of the ecosystem services, habitat, cultural values, and plant conservation strategies of the future Melbourne Gardens is needed to ensure that the diverse needs of both humans and non-human animals are met into the future. A trait-based approach to explore questions around desired plant conservation outcomes, ecosystem services, habitat and recreational values will develop understanding of the benefits provided by the Gardens while the species composition is changing. Understanding how the public and stakeholder groups may respond to these new plant species is also important. Engagement with all relevant parties is needed to be able to make informed choices from this large pool of potential taxa.

3) Microclimate mapping - how may this influence future plant selection?

   Continuing to build understanding of the microclimates within the Gardens will help with classifying distinct environmental conditions within the Gardens that in turn can inform plant choices for particular sites. The cultivation experience and observations of plant performance for species growing in different microclimates can also inform the future degree of risk for certain taxa to changing temperatures. It is important that observational and measured data is collected and maintained in centralised databases such as the Living Collections database to inform future management of Melbourne Gardens.

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Appendix 1: Glossary

BIOCLIM 5: Mean maximum temperature of warmest month.

BIOCLIM 11: Mean minimum temperature of coldest quarter.

BIOCLIM 12: Mean annual precipitation.

BIOCLIM 17: Precipitation of the driest quarter.

Niche: The environmental conditions that a plant can tolerate.

Appendix 2: The 45 most common arborescent species in Melbourne Gardens

Table 7 – The count and rating under the moderate climate change scenario of the most common tree species in the Melbourne Gardens.

Row Labels	Grand Total	Purple	Blue	Aqua	Green	Yellow	Orange	Red
Cordyline australis	272					X		
Archontophoenix cunninghamiana	119				X			
Livistona australis	84				X			
Pittosporum undulatum	73				X			
Trachycarpus fortunei	66				X			
Syzygium smithii	58				X			
Polyscias elegans	58				X			
Rhopalostylis sapida	49							X
Cyathea sp.	49							
Phoenix canariensis	40				X			
Myrsine howittiana	37					X		
Hymenosporum flavum	36				X			
Eucalyptus camaldulensis	34				X			
Cordyline sp.	34							
Acacia melanoxylon	32					X		
Dicksonia antarctica	31					X		
Cyathea cooperi	31				X			
Aloe barberae	31				X			
Bursaria spinosa	29					X		
Elaeocarpus reticulatus	28				X			
Araucaria cunninghamii	28				X			
Ficus macrophylla subsp. *macrophylla*	27				X			
Phoenix reclinata	26				X			

Table 7 - continued

Row Labels	Grand Total	Purple	Blue	Aqua	Green	Yellow	Orange	Red
Chamaerops humilis	26				X			
Tristaniopsis laurina	24				X			
Sophora microphylla	24					X		
Melia azedarach	24				X			
Cyathea brownii	24				X			
Agathis robusta subsp. *robusta*	24				X			
Butia odorata	24				X			
Archontophoenix sp.	24							
Ulmus procera	23							X
Dracaena draco	23				X			
Callistemon sieberi	23					X		
Podocarpus totara	22							X
Podocarpus elatus	22				X			
Stenocarpus sinuatus	22				X			
Brachychiton acerifolius	22				X			
Syzygium paniculatum	21				X			
Eucalyptus pauciflora	21					X		
Brachychiton rupestris	21				X			
Ginkgo biloba	20			X			X	
Corynocarpus laevigatus	20					X		
Cussonia spicata	20				X			
Acacia implexa	20					X		

Appendix 3: Change over time in temperature and rainfall in the Melbourne area

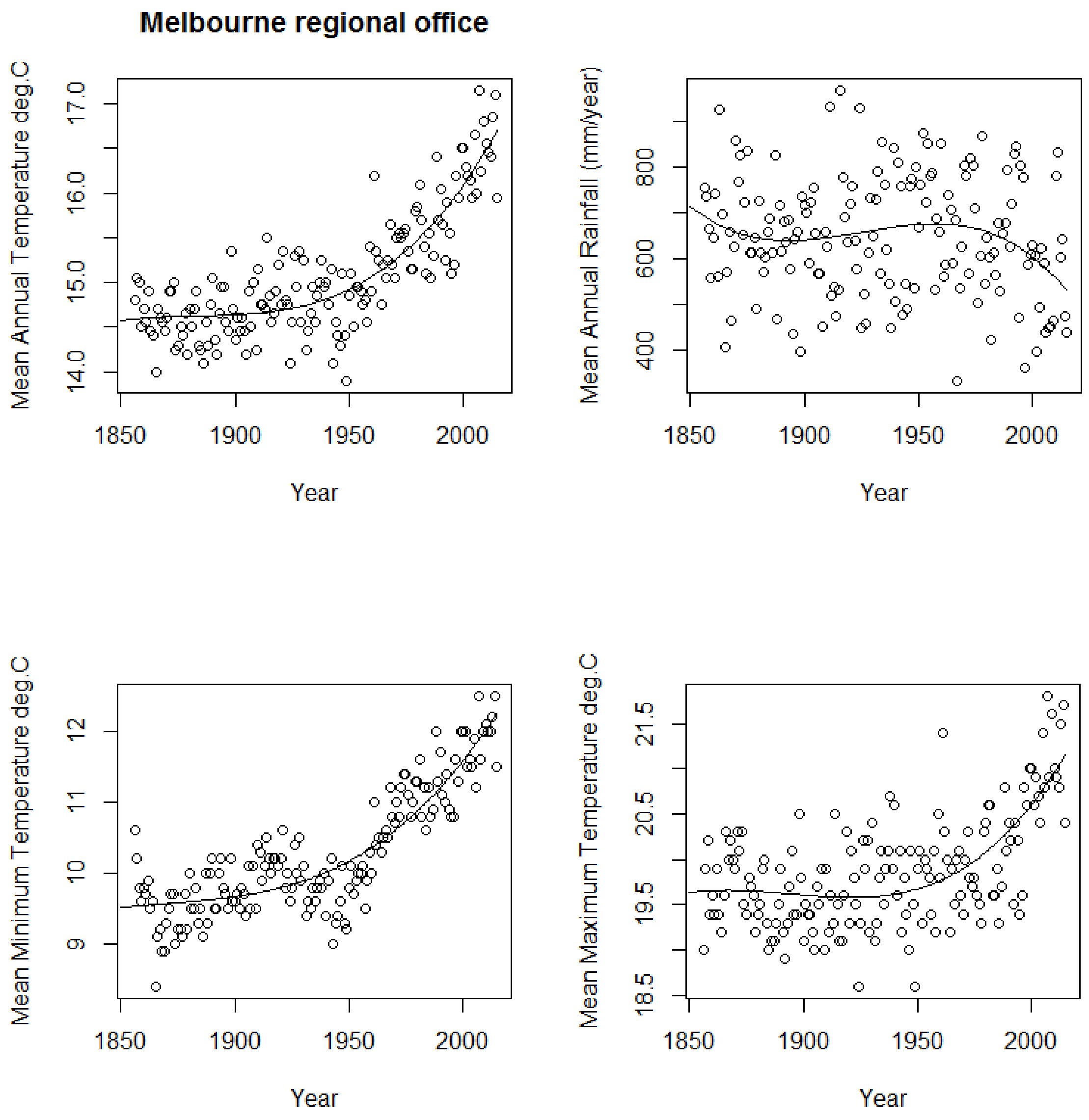

Figure 12 – Change in temperature and rainfall in the Melbourne area over time. Polynomial regression lines of best fit (including quadratic and cubic terms) have been shown.

Appendix 4: Mean annual temperature and rainfall projections under different emissions scenarios

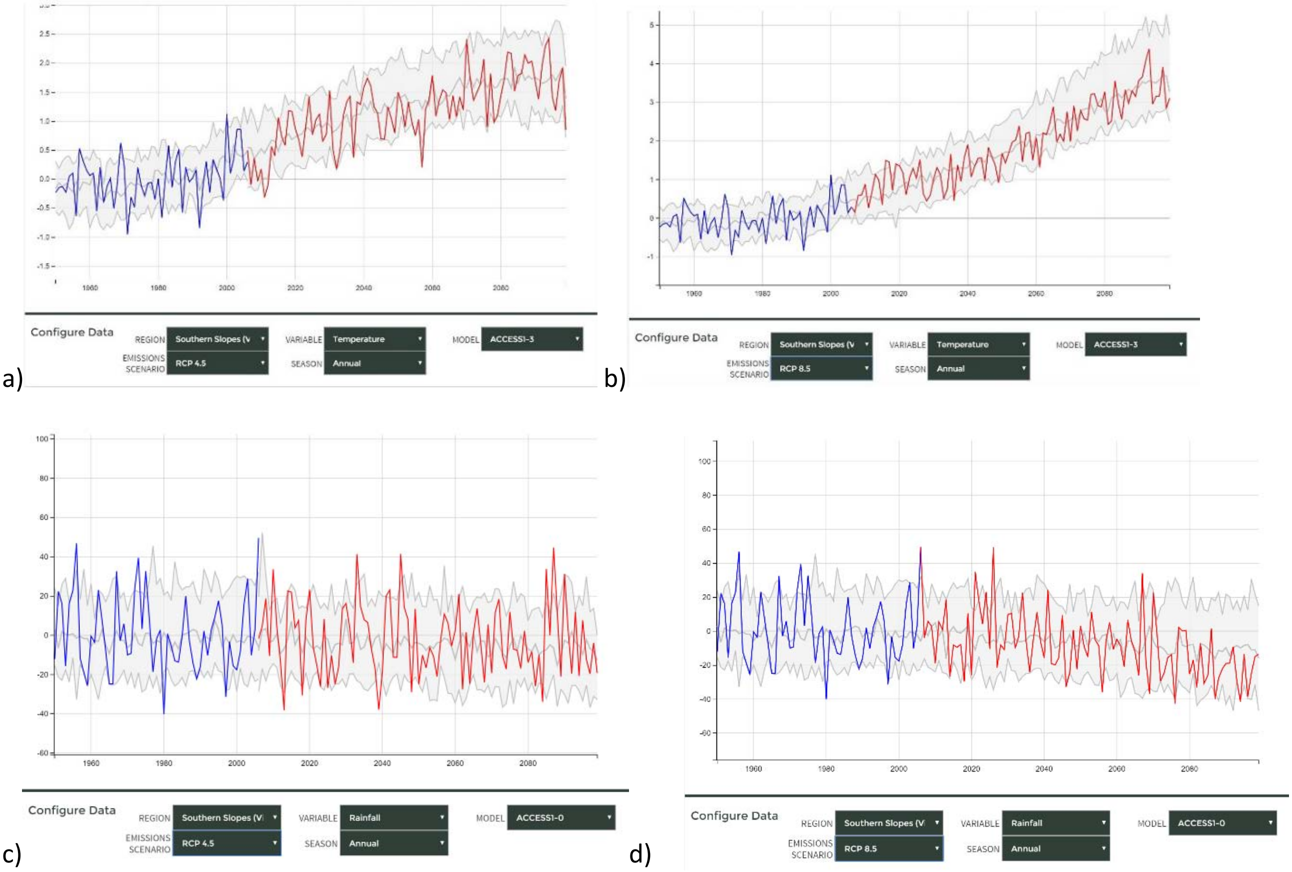

Figure 13 – Change in mean annual temperature (a & b) and rainfall (c & d) for the Southern Slopes region, including Melbourne, projected to 2070 under a & c) the RCP 4.5 moderate emissions scenario and the b & d) business as usual RCP 8.5 emissions scenario. The average, 10th percentile and 90th percentile of climate change models are shown, overlaid by the single ACCESS1-3 model by CSIRO/BOM. Generated using the Time Series Explorer tool provided by climatechangeinaustralia.gov.au

Appendix 5: BIOCLIM 1

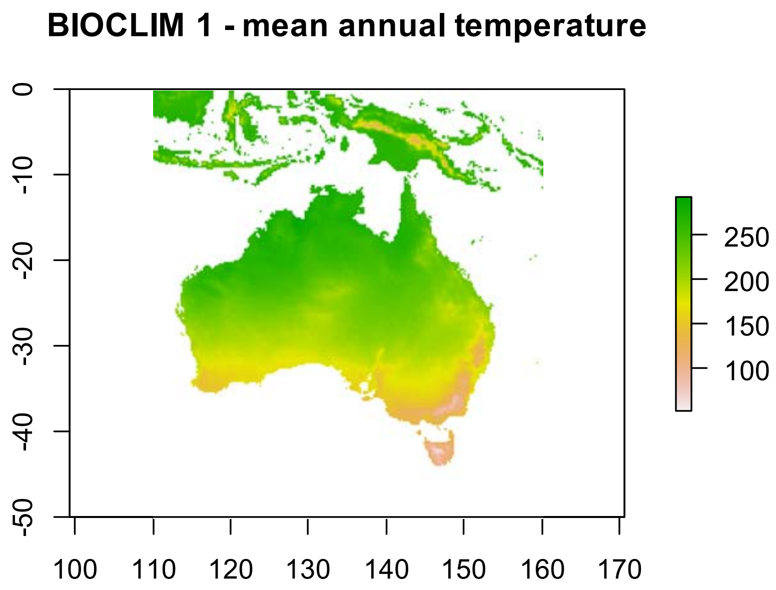

Figure 14 – BIOCLIM 1 (mean annual temperature – in raw Bioclim units which is in ° C multiplied by 10) values across Australia.

Appendix 6: Global map of tree species inventories

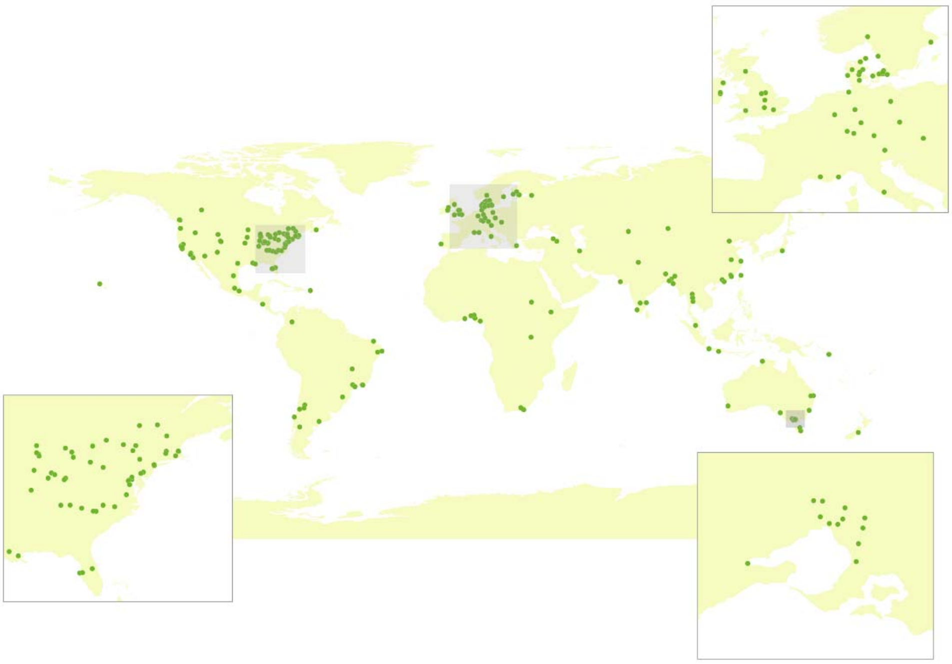

Figure 15 – Map showing the location of global tree inventories.