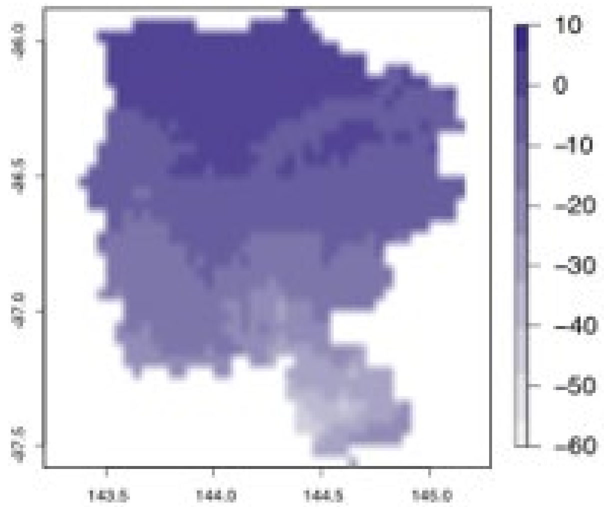
COOL-IT TREE SELECTION

Evaluation of street trees for future climate in the Mallee, Loddon-Campaspe and Central Highlands regions



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Prepared for
Central Victoria Greenhouse Alliance (CVGA)

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Executive Summary

The Cool-It project is a partnership between the Central Victorian Greenhouse Alliance (CGA) and 8 local governments in the region. The project aims to plant trees in locations where social vulnerability and heat exposure overlap, in the shires of Buloke, Pyrenees, Gannawarra, Ararat, Central Goldfields, Macedon Ranges, Hepburn and Mount Alexander. Selection of tree species that are resilient to future climate scenarios is critical for planting success.

The goal of tree selection for the Cool It project was to evaluate and recommend tree species for urban planting, based on their likely resilience to a business as usual, climate scenario in 2050 (i.e. extreme RCP 8.5 emission scenario).

We evaluated a long list of 423 street and park trees planted in Central Victorian towns and cities with climates that are analogous to future climate in participating shires. From this list we developed a short list of 100 candidate street and park trees for detailed evaluation of their vulnerability to future climate. This short-list included 50 species currently planted by participating Shires and 50 new "experimental" species.

The following document and the supplied Species Selection Matrix, provides a ranking of all species in terms of their vulnerability to future climate in each region, recommends species for each region that are likely to most resilient to future climate and provides additional information on species attributes to aid tree selection for planting in urban streets and parks. In addition, regional maps are provided that illustrate projected change in mean annual temperature, annual rainfall and maximum temperature of the warmest month in 2050, under extreme climate scenario (RCP 8.5)

Introduction

More than one third of all public trees (35% species) in Australia cities are at high risk from increased temperatures by 2070, in a 'business-as-usual' emissions scenario (Kendal et al. 2017). To maintain and enhance tree cover for urban cooling in regional centers, the current tree stock in parks and streetscapes must be shifted towards a wider diversity of climate resilient species. Sound species selection requires optimising both the benefits from urban trees and their survival under future climate scenarios.

This document presents results of tree selection for Phase 2 of the Cool it Project; an evaluation of street trees for urban cooling and future climate resilience in the Mallee, Loddon-Campaspe and Central Highlands regions. These three Victorian Regional Partnership (VRP) regions incorporate eight Shires participating in the Cool It project (Phase 2): Central Goldfields, Macedon Ranges and Mount Alexander Shire Councils in the Loddon-Campaspe region, Gunnawarra and Buloke Shire Councils in the Mallee region; and Ararat, Hepburn and Pyrenees Shire Councils in the Central Highlands region (Figure 1). While Loddon Shire was not a participant in this project, results from the Loddon-Campaspe region will be relevant to this Shire.

Figure 1 *Map of the eight Local Government Areas (LGAs) that are the focus of tree selection in Cool It Stage 2.*

This document also includes recommendations for increasing resilience of street tree plantings. The methodology used to select climate resilient street trees for urban cooling is briefly outlined below. **Accompanying this document is a searchable excel spreadsheet of climate resilient trees for councils to use across the region in streetscapes, parks and gardens.** This spreadsheet also includes species that are currently planted in participating Shires.

Methodology

The methodology followed for data collection and analysis are summarised in Figure 2 and briefly discussed below.

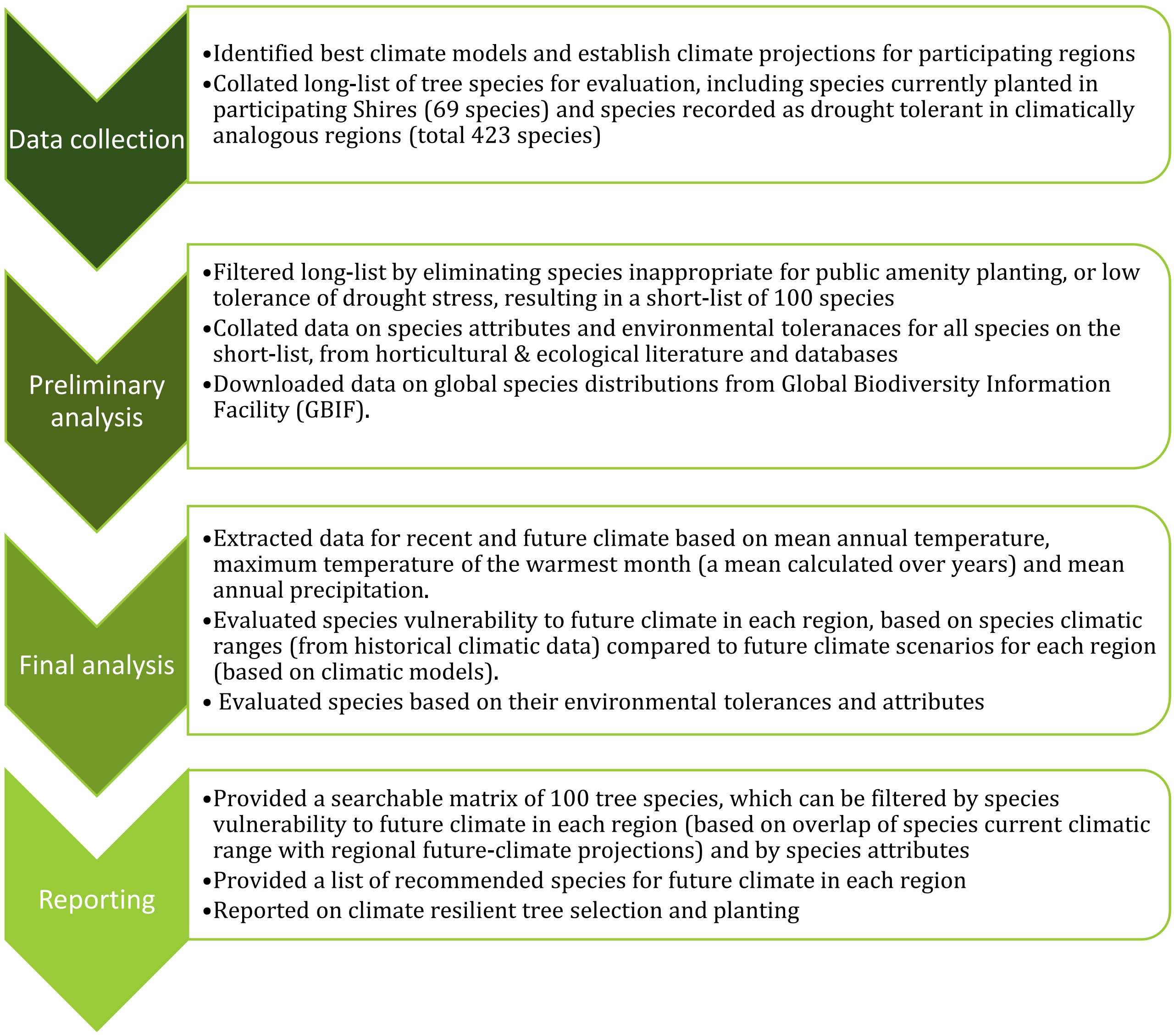

Figure 2 *Process for recommending potential street trees for future climate in 2050 (RCP 8.5)*

Collating tree lists for evaluation

We collated a long list of 423 potential tree species, including 69 species on tree inventories for seven of the eight participating Shires (we did not obtain a list for Hepburn Shire), and an additional 354 experimental street trees with potential for climate resilient urban plantings.

The experimental list was derived from databases and lists of street or park tree species recorded as: tolerant of future climate within the region (Ballarat, Kendal et al, 2017), species recorded as drought tolerant in Melbourne (University of Melbourne, 2012) or species recorded as drought tolerant in cities and towns that are climate analogues for future climate towns within the study region, including Tehran, Dubbo, Adelaide and Canberra (Aszargardeh, 2014; Dubbo Regional Council, 2015; Government of SA, 2016, Kendal et al, 2017 respectively).

We developed a short-list of experimental Street and Park trees for evaluation by eliminating "red-flag" species, inappropriate for public amenity planting due to: high potential for becoming invasive, high allergenic properties and high limb-fall risk. We also eliminated species known to have low or average tolerance of drought stress, low tolerance of cold (minimum temperature >-3° C) and tree species too short to provide value as shade trees (i.e < 5 m maximum height).

Our final short-list of 100 tree species for evaluation included 50 species on Council lists[1] plus 50 additional experimental species. These experimental species were selected to optimise benefits from urban plantings and persistence under future climate scenarios.

Collating species data

For all species on the short list we downloaded data on global species distributions from Global Biodiversity Information Facility (GBIF, https://www.gbif.org). This occurrence data captures species climatic range. Cultivars were included as species, as data on cultivar provenance and climatic suitability are limited.

Species attribute data, for all species on the short-list was collated from plant selection databases, nursery catalogues and scientific papers (listed in Appendix II). Environmental attributes recorded were: tolerance to wind, soil compaction and waterlogging (where 0=sensitive, 1=low tolerance, 2= moderate and 3=high tolerance[2]), light (shade, semi-shade and full sun), soil pH and minimum temperature. Undesirable attributes recorded were: invasive potential, allergenicity, cultivation issues, limb fall risk (where 0=no risk, 1=low risk , 3=high risk). Physical attributes were: height (minimum and maximum), canopy dimensions and seasonality (Evergreen/deciduous). We also recorded species family, origin (Exotic/native) and whether it was endemic to Victoria (y/n). Because the Burnley Plant Guide (University of Melbourne, 2012) represented the most comprehensive coverage of all species on our final list, for consistency we used this as our primary source of species data, filling in any gaps from other data sources (listed in Appendix II) where required.

Species attributes that were beyond the scope of this project, though important for final selection for urban planting include aesthetic and cultural value, susceptibility to pests and

[1] We evaluated 30 species most likely to be planted by participating Shires in 2020-21 (Appendix I) for Milestone 1 of the Cool It project. For consistency, we have reevaluated these species for Milestone 2 of the project, using improved modelling methods and data, along with the an additional 20 Council species (included at least once on planting lists of participating Shires and with a moderate likelihood of planting in 2020-21).

2 Species tolerance of an environmental factor is "the ability to withstand stress without suffering serious, irreversible damage" (Brun, 2016).

diseases, and tolerance of conditions particular to high density urban environments (e.g. air pollution, limited root space, periodic waterlogging and soil contaminants).

Importantly for the Cool It project, ranking species by their urban cooling benefits was beyond the scope of this report. Trees provide urban cooling through both transpiration and shade. Transpiration rates were unavailable for most species on our short-list. Further, many species shut-down transpiration (by closing stomata) at high temperatures and low soil moisture values, so cooling provision from transpiration is highly variable trait over the course of a hot day. Estimating shade provision requires knowledge of the leaf area (leaf area index = leaf area per area of ground) and the canopy area. Leaf area index values were also difficult to source for the majority of the trees on our short-list. Councils will need to make their own decisions about canopy properties when selecting trees for urban cooling.

Species evaluation

We used Worldclim climatic data to evaluate the short-list of street and park trees for resilience to a business as usual, climate scenario in 2050 (i.e. extreme RCP 8.5 emission scenario). Climatic scenarios project the ways that global temperature increases will perturb our current climate into the future. Bioclimatic studies combine climate data and species distribution data used to evaluate species vulnerability to future climate, by characterising species climatic range (climate envelopes) and using these ranges to project species potential future distributions under various climate emission scenarios. This method has been used in a wide range of bioclimatic evaluations of tree species, such as: identifying trees likely to be less vulnerable to Melbourne's future climate for the Melbourne Urban Forest Strategy (Kendal et al 2016), assessing probability of finding climatically suitable habitat in each region for urban Australian trees species (Burley et al, 2019) and evaluating candidate forestry species for assisted migration in Manitoba (Park et al, 2018).

Climate data were used to compare the recent historical climate (1970-2000) to the newest generation of future climate projections (2041-2060), under a high carbon emissions scenario (RCP 8.5, https://worldclim.org/). This scenario is the current global current trajectory, unless fast and drastic global action is taken. Climate projections values were extracted from the global scenario (model BCC-CSM2-MR_ssp585_2041-2060)[3],

Temperature and rainfall have the biggest impact on tree survival. Mean annual temperature and annual rainfall are recognised as being highly correlated with plant species climate vulnerability across species ranges and were selected as the primary variables for species climate vulnerability ranking in the current project. We also used mean temperature of the warmest month to capture the effect of heat stress during more extreme weather events. Climate variables were extracted from BIOCLIM rasters.[4]

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3 The global climate model used was BCC-CSM2-MR_ssp585_2041-2060. While downscaled high-resolution climate change simulations are available for Victoria, from CSIRO's Climate Science Centre, we could not use these, as we required congruence with global species distribution data. We chose the recently updated CMIP6 global model BCC-CSM2-MR_ssp585_2041-2060 because it provides average results compared to the other climate models available and it more closely matches the Australian climate. CMIP6 global models predict slightly hotter temperatures than the downscaled Victorian models.

4 Global bioclimatic variables from BIOCLIM are derived from the monthly temperature and rainfall values in order to generate more biologically meaningful variables. These are often used in species distribution modeling and related ecological modeling techniques. The bioclimatic variables represent annual trends.

By taking the current climatic range of a species[5] and comparing it to the future climate in the Mallee, Loddon Campaspe and the Central Highlands [6] we were able to estimate how much climatic overlap there was between species current climatic range and the future climatic ranges of the three regions, where 0% = no overlap and 100% = total overlap. For scores of 100, the overlap was either because the species range was broader than the regional range, or the reverse, the regional range was broader than the species range.

Species likely vulnerability to the future climate in each region was ranked, based on estimates of percentage overlap between species current and its future climatic range. Overlap for mean annual temperature and annual rainfall in each region was calculated for species in each region.

A key outcome is a searchable species selection matrix for Shires to use in tree selection, where species can be screened by their risk of future climate, utility for urban cooling, environmental tolerances and general attributes.

Because of moderate uncertainty around species tolerance scores quantified from the literature, focus selection on the 'very tolerant' and eliminate 'very sensitive' species as recommended by Brun (2016). Ideally, species selection should be supported by long-term monitoring and adaptive management. This is particularly the case for novel species plantings, where the limits of horticultural utility and resilience are largely unknown.

This species selection identifies tree species that require no or little support as they mature into in hotter, drying climates.

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5 Four steps were involved in calculating the overlap between the current climatic range of 100 species with the future climatic ranges of the three regions: 1) estimate species mean annual temperature and mean annual precipitation, from global species distribution records in the Global Biodiversity Information Facility (GBIF) database; 2) Calculate a conservative species 'window' for each climate variable, calculated as ± one standard deviation from the mean. This 'window' was a conservative estimate of species climatic range, as it contains 68% of species records; 3) Calculate a 'window' for the projected climate in each region as ± one standard deviation from mean annual temperature and mean annual precipitation for each region; 4) Calculate percent overlap between the window for each species with the regional window for each climate variable.

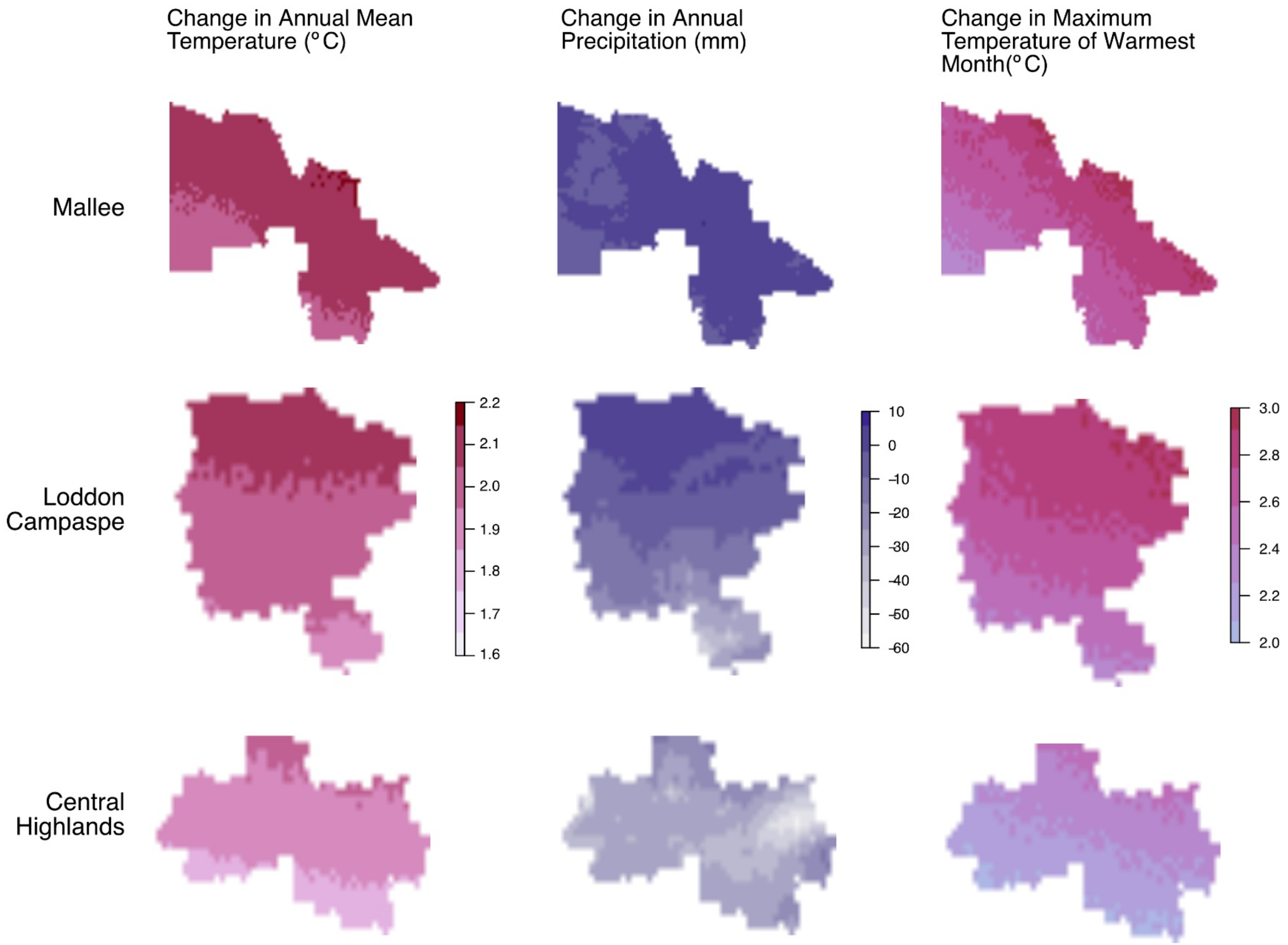
Regional climate change projections

Understanding variation in regional climate trends is important for appropriate tree selection within each region. Average values for three climate variables (mean annual temperature, annual rainfall and maximum monthly temperature) are provided in **Table 1**. Before following recommended trees for future climate in each region, it is important to be aware of regional variation. Average climate values are good at picking up general trends but they fail to identify how much variation there is in that trend. In Victoria, temperatures are predicted to rise but these will happen at varying intensities across the different regions. Variation in projected changes in climate variables is illustrated in (**Figure 3**).

Table 1 *Mean project climate values for three regions in 2041-2060 (under extreme climate change, RCP 8.5)*

		Average 1970-2000	Average 2050	**Average change**	Standard deviation change
Annual Mean Temperature (ºC)	Mallee	16.4	18.5	**2.1**	0.04
	Loddon	14.6	16.6	**2.0**	0.04
	Highlands	12.8	14.7	**1.9**	0.05
Maximum Temperature of Warmest Month (ºC)	Mallee	31.7	34.5	2.67	0.04
	Loddon	29.4	32.1	2.70	0.15
	Highlands	26.2	28.5	2.25	0.11
Annual Precipitation (mm)	Mallee	339	340	**0.2**	2.4
	Loddon	535	527	**-8.7**	9.8
	Highlands	675	644	**-30.8**	6.6
Precipitation of Driest Quarter (mm)	Mallee	64	67	**2.7**	2.3
	Loddon	97	99	**1.5**	2.2
	Highlands	117	120	**2.6**	4.9

Figure 3 *Projected changes in climate in the three regions (mean annual temperature, mean rainfall and mean maximum temperature) in 2050, under extreme climate scenario (RCP 8.5)*



Recommended trees for the regions

Recommended trees for Mallee region (2050)

A total of forty-five species were identified with low vulnerability to future climate in the Mallee region, estimated from mean annual temperature and mean annual rainfall. But only three species were identified as having low vulnerability to high maximum temperatures: Coobah (*Acacia salcina*), Whitewood (*Atalaya hemiglauca*) and Round-leaved Mallee (*Eucalyptus rotundifolia*).

Of the tree species rated as having a high likelihood of planting in the Buloke Shire in 2020-21, only four species are ranked as having a low vulnerability to future climate. These are the Crepe Myrtle (*Lagerstroemia indica*), Peppercorn Tree (*Schinus molle*), Carob (*Ceratonia siliqua*) and Callery Pear (*Pyrus calleryana*). And only two popular species in the Gunnawarra Shire are ranked with low vulnerability to future climate: Crepe Myrtle and Callery Pear.

While some species ranked as vulnerable to future climate can still be planted in the regions, they should only be considered for planting in sites with amenable microclimates and soils and if supportive horticultural practices such as irrigation and soil improvement can be maintained. It is highly recommended that Shires in the Mallee region consider broadening their tree selection to include species on the list of recommended species below (**Table 1**).

*Table 2 Tree species rated as low vulnerability to future climate in the Mallee region (*Species with best rating for mean annual temperature and mean annual precipitation; ** Species with low vulnerability to high maximum temperatures)*

SPECIES	COMMON NAME
Acacia pendula	Weeping Myall
*Acacia salicina***	Coobah, Willow Wattle
Allocasuarina inophloia	Stringybark She-oak
Allocasuarina luehmannii	Buloke
Allocasuarina torulosa	Forest Oak
Angophora costata	Rose Apple
*Atalaya hemiglauca***	Whitewood
Callistemon citrinus	Lemon Bottlebrush
Callistemon viminalis	Weeping Bottlebrush
Callitris canescens	Scrubby cypress pine
Callitris columellaris	White Cypress Pine, Coast Cypress Pine
Callitris glaucophylla	White Cypress
*Callitris preissii**	Rottnest Island Pine
Ceratonia siliqua	Carob
Corymbia aparrerinja	Ghost Gum
Corymbia citriodora	Lemon-scented Gum
Corymbia maculata	Spotted Gum
Eriobotrya japonica	Loquat
Eucalyptus cladocalyx	Sugar Gum
*Eucalyptus leucoxylon**	Yellow Gum
Eucalyptus macrandra	Long-flowered Marlock
Eucalyptus megacornuta	Warty Yate
*Eucalyptus orbifolia***	Round-leaved Mallee
Eucalyptus pachyphylla	Red Bud Mallee
Eucalyptus platypus	Round-leaved Moort
Eucalyptus porosa	no common name
Ficus rubiginosa	Port Jackson Fig
Geijera parviflora	Wilga
Hakea laurina	Pincushion Hakea

Jacaranda mimosifolia	Jacaranda
Lagerstroemia indica	Crepe Myrtle
Leptospermum laevigatum	Coastal Tea-tree
Lophostemon confertus	Brush Box
Melaleuca halmaturorum	Salt Paperbark
*Melaleuca lanceolata**	Moonah
Melaleuca linariifolia	Flaxleaf Paperbark
Melaleuca styphelioides	Prickly-leaved Paperbark
Melia azedarach	White Cedar
Metrosideros excelsa	Pohutukawa
*Myoporum insulare**	Common Boobialla
*Pinus canariensis**	Canary Islands Pine
Pistacia chinensis	Chinese Pisctachio
Pyrus calleryana	Callery Pear
*Schinus mole**	Peppercorn Tree
Ulmus parvifolia	Chinese Elm

Recommended trees for Loddon-Campaspe region (2050)

A total of thirty-two species were identified as having a low vulnerability to future mean annual temperature, mean annual rainfall and to mean maximum temperatures in the Loddon-Campaspe region in 2050, under an extreme climate change scenario (RCP8.5; species identified with ** in **Table 3**). Overall, ninety-four species were identified with lower vulnerability to future climate in the Loddon-Campaspe region, estimated from mean annual temperature and mean annual rainfall.

Of the tree species rated as having a high likelihood of planting in Shires of the Loddon-Campaspe region, twelve species in the Central Goldfields Shire in 2020-21, and twenty-three species in the Mount Alexander Shire were ranked as having a lower vulnerability to future climate (listed in **Table 2** and **Table 3** respectively). Additional species worth exploring for planting in these shires, diversify the urban forest with climate resilient species, are recommended in (Table 4).

Table 3 Central Goldfields Shire species with high likelihood of planting and with lower vulnerability to future climate.

SPECIES	COMMON NAME
Brachychiton populneus	Kurrajong
Callistemon citrinus	Lemon Bottlebrush
Callistemon viminalis	Weeping Bottlebrush
Eucalyptus leucoxylon	Yellow Gum
Eucalyptus tricarpa	Red Ironbark
Ficus rubiginosa	Port Jackson Fig
Melaleuca linariifolia	Flaxleaf Paperbark
Prunus cerasifera	Myobalan Plum
Pyrus calleryana	Callery Pear
Quercus palustris	Pin Oak
Ulmus parvifolia	Chinese Elm
Zelkova serrata	Japanese Elm

Table 4 *Mount Alexander Shire species with high likelihood of planting and with lower vulnerability to future climate*

Acacia melanoxylon	Blackwood
Angophora costata	Rose Apple
Brachychiton populneus	Kurrajong
Callistemon citrinus	Lemon Bottlebrush
Celtis australis	European Nettle Tree
Eucalyptus leucoxylon	Yellow Gum
Eucalyptus melliodora	Yellow Box
Eucalyptus polyanthemos	Red Box
Eucalyptus sideroxylon	Mugga Ironbark
Fraxinus angustifolia subsp. oxycarpa	Claret Ash
Fraxinus excelsior	Golden Ash
Geijera parviflora	Wilga
Koelreuteria paniculata	Golden Rain Tree
Lagerstroemia indica	Crepe Myrtle
Malus ioensis	Prairie Crabapple
Melaleuca styphelioides	Prickly-leaved Paperbark
Melia azedarach	White Cedar
Pistacia chinensis	Chinese Pisctachio
Prunus cerasifera	Myobalan Plum
Pyrus calleryana	Callery Pear
Quercus cerris	Turkey Oak
Quercus palustris	Pin Oak
Ulmus parvifolia	Chinese Elm

*Table 5 Tree species rated as low vulnerability to future climate in the Loddon-Campaspe region (*Species with best rating for mean annual temperature and mean annual precipitation; ** Species with lowest vulnerability to high maximum temperatures)*

SPECIES	COMMON NAME
Acacia melanoxylon	Blackwood
*Acacia pendula***	Weeping Myall
*Acacia salicina***	Coobah, Willow Wattle
Agonis flexuosa	Willow Myrtle
*Allocasuarina inophloia***	Stringybark She-oak
*Allocasuarina luehmannii***	Buloke
Allocasuarina torulosa	Forest Oak
*Allocasuarina verticillata***	Drooping Sheoke
Angophora costata	Rose Apple
Angophora hispida	Dwarf Apple
Atalaya hemiglauca	Whitewood
Banksia marginata	Silver Banksia
*Brachychiton populneus***	Kurrajong
Callistemon citrinus	Lemon Bottlebrush
*Callistemon viminalis***	Weeping Bottlebrush
*Callitris canescens***	Scrubby cypress pine
*Callitris columellaris***	White Cypress Pine, Coast Cypress Pine
*Callitris endlicheri***	Black Cypress
*Callitris glaucophylla***	White Cypress
*Callitris preissii***	Rottnest Island Pine
*Callitris rhomboidei**	Port Jackson pine
*Celtis australis***	European Nettle Tree
*Ceratonia siliqua***	Carob
*Cercis siliquastrum***	Judas Tree
Corymbia aparrerinja	Ghost Gum
Corymbia citriodora	Lemon-scented Gum
Corymbia ficifolia	Red Flowering Gum
Corymbia maculata	Spotted Gum
Cupressus lusitanica	Mexican Cypress
*Cupressus macrocarpa**	Monterey Cypress
*Eriobotrya japonica**	Loquat
Eriolobus trilobatus	Lebanese Wild Apple, Upright Crabapple
*Eucalyptus albens***	White Box
Eucalyptus arenacea	Desert stringybark
Eucalyptus baueriana	Blue box, Round-leaved box
*Eucalyptus behriana***	Bull mallee
*Eucalyptus cladocalyx***	Sugar Gum
*Eucalyptus conferruminate**	Bushy Yate, Bald Island Marlock
*Eucalyptus cornuta**	Yate
*Eucalyptus cosmophylla**	Cup Gum
*Eucalyptus diversifolia**	Soap mallee, Coastal white mallee
*Eucalyptus dolichorhyncha***	Fuschia Gum
*Eucalyptus leucoxylon***	Yellow Gum
*Eucalyptus macrandra***	Long-flowered Marlock
*Eucalyptus megacornuta**	Warty Yate
*Eucalyptus melliodora***	Yellow Box
*Eucalyptus newbeyi**	Newbey's Mallet
*Eucalyptus occidentalis**	Flat-topped Yate
Eucalyptus pachyphylla	Red Bud Mallee
*Eucalyptus platypus**	Round-leaved Moort
Eucalyptus polyanthemos	Red Box
*Eucalyptus porosa***	ncn
Eucalyptus saxatilis	Suggan Buggan Mallee
Eucalyptus scoparia	Wallangarra White Gum
*Eucalyptus sideroxylon***	Mugga Ironbark
Eucalyptus tricarpa	Red Ironbark
Ficus rubiginosa	Port Jackson Fig

*Fraxinus angustifolia subsp. Oxycarpa**	Claret Ash
Fraxinus excelsior	Golden Ash
Fraxinus pennsylvanica	Green Ash
*Geijera parviflora***	Wilga
Ginkgo biloba	Gingko
*Gleditsia triacanthos**	Honey Locust
*Hakea laurina**	Pincushion Hakea
Jacaranda mimosifolia	Jacaranda
*Koelreuteria paniculata***	Golden Rain Tree
Lagerstroemia indica	Crepe Myrtle
Leptospermum laevigatum	Coastal Tea-tree
Lophostemon confertus	Brush Box
*Maclura pomifera***	Osage Orange
*Melaleuca halmaturorum***	Salt Paperbark
*Melaleuca lanceolata***	Moonah
Melaleuca linariifolia	Flaxleaf Paperbark
Melaleuca styphelioides	Prickly-leaved Paperbark
Melia azedarach	White Cedar
Metrosideros excelsa	Pohutukawa
*Myoporum insulare**	Common Boobialla
*Pinus canariensis**	Canary Islands Pine
*Pinus pinea***	Stone Pine
*Pistacia chinensis***	Chinese Pisctachio
Prunus cerasifera	Myobalan Plum
Pyrus calleryana	Callery Pear
*Quercus canariensis**	Algerian Oak
Quercus cerris	Turkey Oak
Quercus coccinea	Scarlet Oak
*Quercus ilex**	Holly Oak
Quercus palustris	Pin Oak
Quercus pyrenaica	Pyrenean Oak
Quercus robur	English Oak, Common Oak
Quercus rubra	Red Oak
*Quercus suber**	Cork Oak
*Schinus mole**	Peppercorn Tree
*Ulmus parvifolia***	Chinese Elm
Zelkova serrata	Japanese Elm

Recommended trees for Central Highlands region (2050)

A total of thirty-one species were identified as having low vulnerability to future mean annual temperature, mean annual rainfall and to mean maximum temperatures in the Central Highlands region in 2050, under an extreme climate change scenario (RCP 8.5; species identified with ** in Table 5). Overall, eighty-three species were identified with lower vulnerability to future climate in the Loddon-Campaspe region, estimated from mean annual temperature and mean annual rainfall.

Of the tree species rated as having a high likelihood of planting in Shires of the Central Highlands region, twenty-four species in the Macedon Ranges Shire in 2020-21, and seven species in Ararat Rural City and eighteen species in the Pyrenees Shire were ranked as having a lower vulnerability to future climate (listed in Table 5 respectively). Additional species are worth exploring for planting in these shires, to diversify the urban forest with climate resilient species, particularly in Ararat Rural City.

Table 6 *Species ranked as having a lower vulnerability to future climate and with a high likelihood of planting in Shires of the Central Highlands region (*)*

Species	Common name	Macedon Ranges Shire	Ararat Rural City	Pyrenees Shire
Acacia melanoxylon	Blackwood	*		
Acer rubrum	Autumn Blaze Maple	*		*
Angophora costata	Rose Apple			*
Banksia marginata	Silver Banksia	*		*
Brachychiton populneus	Kurrajong	*		
Callistemon citrinus	Lemon Bottlebrush	*		
Callistemon viminalis	Weeping Bottlebrush			*
Celtis australis	European Nettle Tree	*		
Corymbia citriodora	Lemon-scented Gum			*
Corymbia ficifolia	Red Flowering Gum	*		*
Corymbia maculata	Spotted Gum	*		*
Eriolobus trilobatus	Lebanese Wild Apple	*		
Eucalyptus leucoxylon	Yellow Gum	*		*
Eucalyptus melliodora	Yellow Box	*		
Eucalyptus polyanthemos	Red Box	*		
Eucalyptus sideroxylon	Mugga Ironbark			*
Fraxinus angustifolia subsp. oxycarpa	Claret Ash	*		*
Fraxinus excelsior	Golden Ash			*
Fraxinus pennsylvanica	Green Ash	*		
Geijera parviflora	Wilga	*		
Gleditsia triacanthos	Honey Locust	*	*	
Hakea laurina	Pincushion Hakea		*	*
Koelreuteria paniculata	Golden Rain Tree	*		
Lagerstroemia indica	Crepe Myrtle		*	*
Lophostemon confertus	Brush Box		*	*
Malus ioensis	Prairie Crabapple	*		
Melia azedarach	White Cedar	*		
Pistacia chinensis	Chinese Pisctachio	*		
Prunus cerasifera	Myobalan Plum		*	
Pyrus calleryana	Callery Pear	*	*	
Quercus canariensis	Algerian Oak	*		
Quercus coccinea	Scarlet Oak			*
Quercus palustris	Pin Oak	*		*
Quercus rubra	Red Oak			*
Ulmus parvifolia	Chinese Elm	*		
Zelkova serrata	Japanese Elm		*	*

Table 7 *Tree species rated as low vulnerability to future climate in the Central Highlands region (*Species with best rating for mean annual temperature and mean annual precipitation; ** Species with lowest vulnerability to high maximum temperatures)*

SPECIES	COMMON NAME
Acacia melanoxylon	Blackwood
Acacia pendula	Weeping Myall
Acacia salicina	Coobah, Willow Wattle
*Acer rubrum**	Autumn Blaze Maple
*Agonis flexuosa**	Willow Myrtle
Allocasuarina inophloia	Stringybark She-oak
Allocasuarina luehmannii	Buloke
*Allocasuarina verticillate**	Drooping Sheoke
Atalaya hemiglauca	Whitewood
Banksia marginata	Silver Banksia
*Brachychiton populneus**	Kurrajong
Callistemon citrinus	Lemon Bottlebrush
Callistemon viminalis	Weeping Bottlebrush
Callitris columellaris	White Cypress Pine, Coast Cypress Pine
*Callitris endlicheri**	Black Cypress
Callitris glaucophylla	White Cypress
*Callitris preissii**	Rottnest Island Pine
*Callitris rhomboidei**	Port Jackson pine
*Celtis australis**	European Nettle Tree
Ceratonia siliqua	Carob
*Cercis siliquastrum**	Judas Tree
Corymbia aparrerinja	Ghost Gum
Corymbia citriodora	Lemon-scented Gum
Corymbia ficifolia	Red Flowering Gum
Cupressus lusitanica	Mexican Cypress
*Cupressus macrocarpa**	Monterey Cypress
Eriobotrya japonica	Loquat
*Eriolobus trilobatus**	Lebanese Wild Apple, Upright Crabapple
*Eucalyptus albens**	White Box
*Eucalyptus arenacea**	Desert stringybark
*Eucalyptus behriana**	Bull mallee
*Eucalyptus cephalocarpa**	Mealy Stringybark
*Eucalyptus cladocalyx**	Sugar Gum
*Eucalyptus conferruminate**	Bushy Yate, Bald Island Marlock
*Eucalyptus cornuta**	Yate
*Eucalyptus cosmophylla**	Cup Gum
*Eucalyptus diversifolia**	Soap mallee, Coastal white mallee
*Eucalyptus dolichorhyncha**	Fuschia Gum
*Eucalyptus leucoxylon**	Yellow Gum
*Eucalyptus macrandra**	Long-flowered Marlock
Eucalyptus mannifera	Brittle Gum
Eucalyptus megacornuta	Warty Yate
*Eucalyptus melliodora**	Yellow Box
*Eucalyptus newbeyi**	Newbey's Mallet
*Eucalyptus occidentalis**	Flat-topped Yate
Eucalyptus platypus	Round-leaved Moort
*Eucalyptus polyanthemos**	Red Box
Eucalyptus saxatilis	Suggan Buggan Mallee
Eucalyptus scoparia	Wallangarra White Gum
*Eucalyptus sideroxylon**	Mugga Ironbark
*Eucalyptus tricarpa**	Red Ironbark
*Ficus rubiginosa**	Port Jackson Fig
*Fraxinus angustifolia subsp. oxycarpa**	Claret Ash
Fraxinus excelsior	Golden Ash
Fraxinus pennsylvanica	Green Ash

Geijera parviflora	Wilga
*Ginkgo biloba**	Gingko
*Gleditsia triacanthos**	Honey Locust
*Hakea laurina**	Pincushion Hakea
*Koelreuteria paniculate**	Golden Rain Tree
Leptospermum laevigatum	Coastal Tea-tree
*Maclura pomifera**	Osage Orange
*Melaleuca halmaturorum**	Salt Paperbark
Melaleuca lanceolata	Moonah
Melia azedarach	White Cedar
*Metrosideros excelsa**	Pohutukawa
*Myoporum insulare**	Common Boobialla
*Pinus canariensis**	Canary Islands Pine
*Pinus pinea**	Stone Pine
*Pistacia chinensis**	Chinese Pisctachio
Prunus cerasifera	Myobalan Plum
Pyrus calleryana	Callery Pear
*Quercus canariensis**	Algerian Oak
Quercus cerris	Turkey Oak
*Quercus coccinea**	Scarlet Oak
*Quercus ilex**	Holly Oak
*Quercus palustris**	Pin Oak
Quercus pyrenaica	Pyrenean Oak
Quercus robur	English Oak, Common Oak
Quercus rubra	Red Oak
*Quercus suber**	Cork Oak
Schinus molle	Peppercorn Tree
*Ulmus parvifolia**	Chinese Elm

Species climatic ranges (1970-2000) compared to projected climatic range for the regions (2050, RCP 8.5)

The following Boxplots illustrate the climatic ranges of the 100 species evaluated for this study, overlain with the projected climatic range for each region in 2050, under an extreme climate scenario (RCP 8.5). These plots can be used to aid Councils to identify species with low vulnerability to future climate, including projected annual precipitation, mean annual temperature and monthly mean maximum. The vertical colour bands the climatic range for reach region in 2050 (i.e. the climatic mean ± 1 standard deviation); the boxes represent the climatic range of each species (median and the interquartile range, representing 50% of species records). To identify species tolerance to future climate simply evaluate whether species climatic range (the box) overlaps regional climatic range (the colour band).[7]

[7] Note, each species climatic range illustrated in these boxplots is narrower than species climatic ranges used to calculate each species vulnerability to future climate, for the Tables above. This is because boxplots represent species climatic range as an interquartile range (each box represents 50% of the species records), whereas standard deviations (representing 68% of species records) were used in the calculations of species climatic overlap with future climate

Figure 4 *Boxplots illustrating species ranges for annual precipitation (mm) for 50 tree species on* ***council inventories****, relative to projected climatic range in each region (Central Highlands purple, Loddon-Campaspe blue, Mallee aqua).*

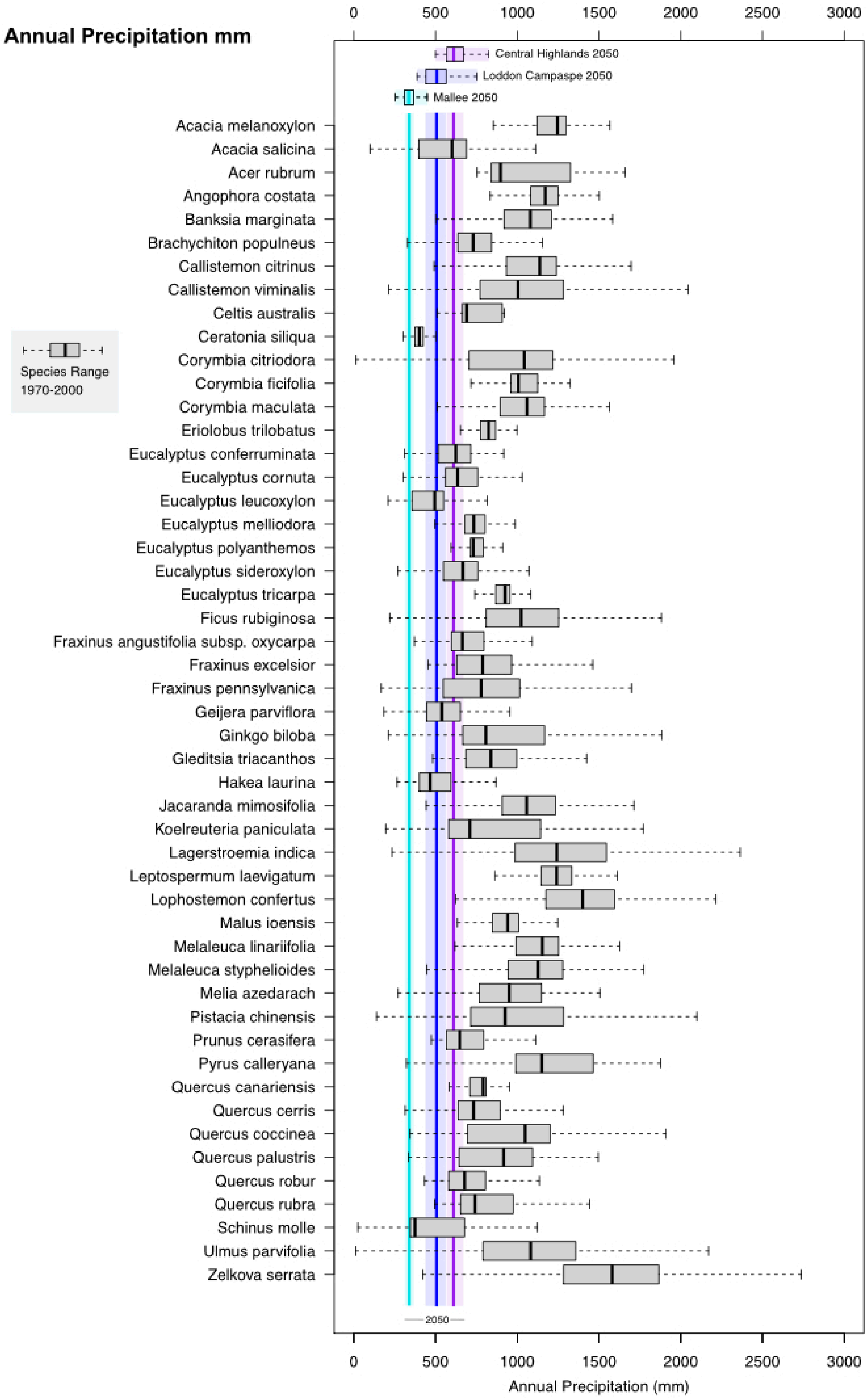


Figure 5 *Boxplots illustrating species ranges for mean annual temperature (°C) for 50 tree species on* ***council inventories****, relative to projected climatic range in each region (Central Highlands purple, Loddon-Campaspe blue, Mallee aqua)*

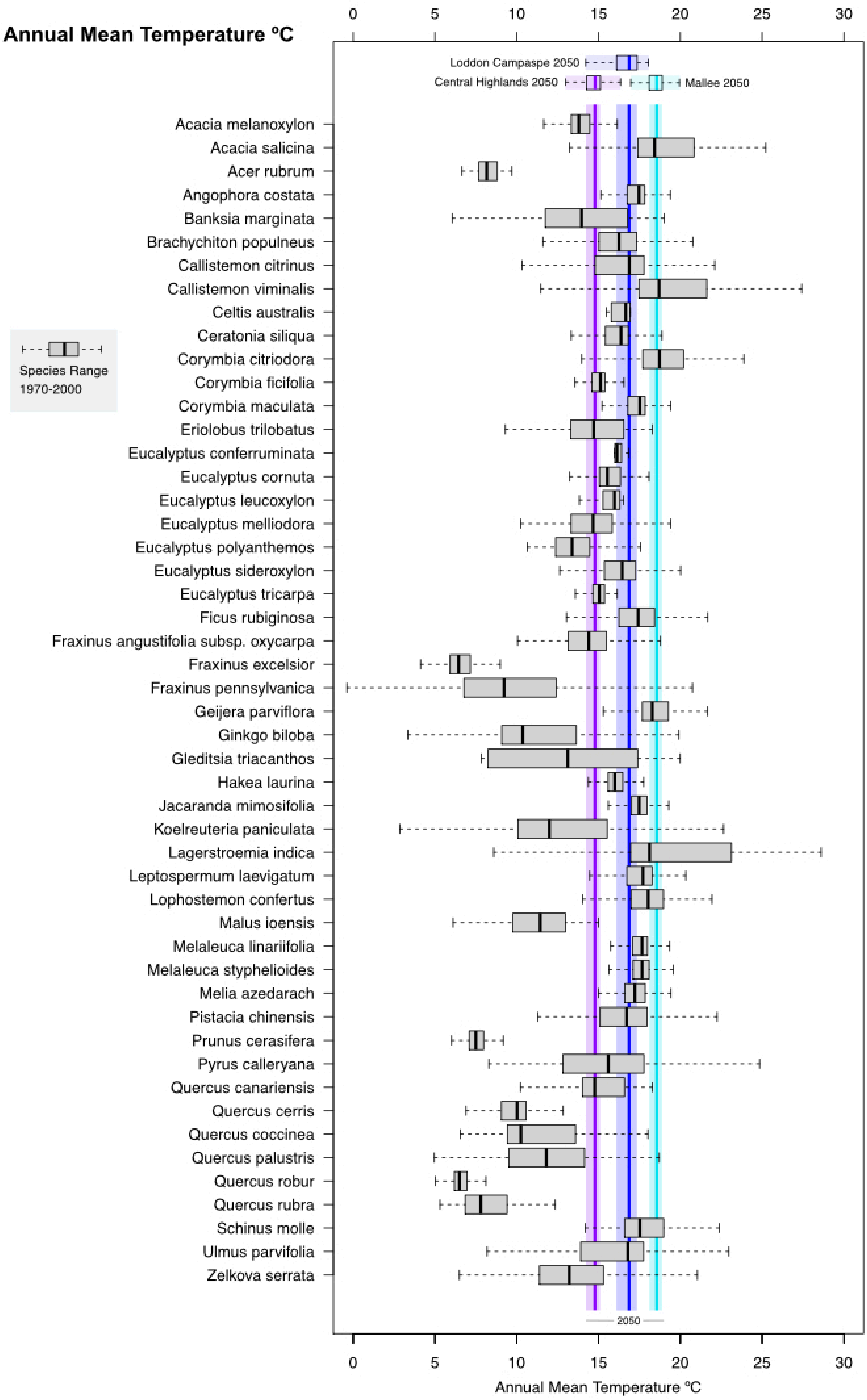


*Figure 6 Boxplots illustrating species ranges for Maximum temperature of warmest month (°C) for 50 tree species on **council inventories**, relative to projected climatic range in each region (Central Highlands purple, Loddon-Campaspe blue, Mallee aqua).*

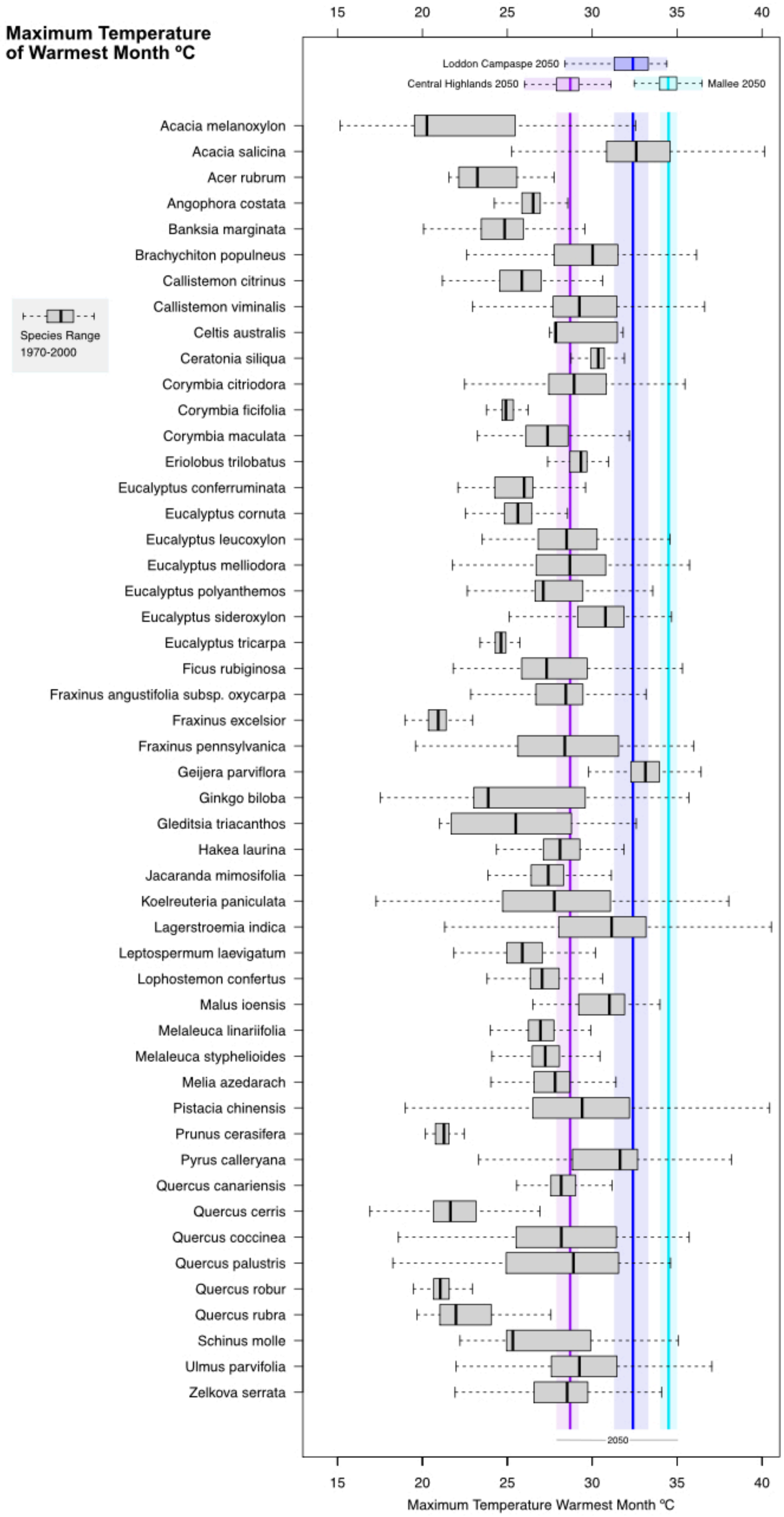


***Figure 7** Boxplots illustrating species ranges for annual precipitation (mm) for 50 tree species on **experimental list**, relative to projected climatic range in each region (Central Highlands purple, Loddon-Campaspe blue, Mallee aqua).*

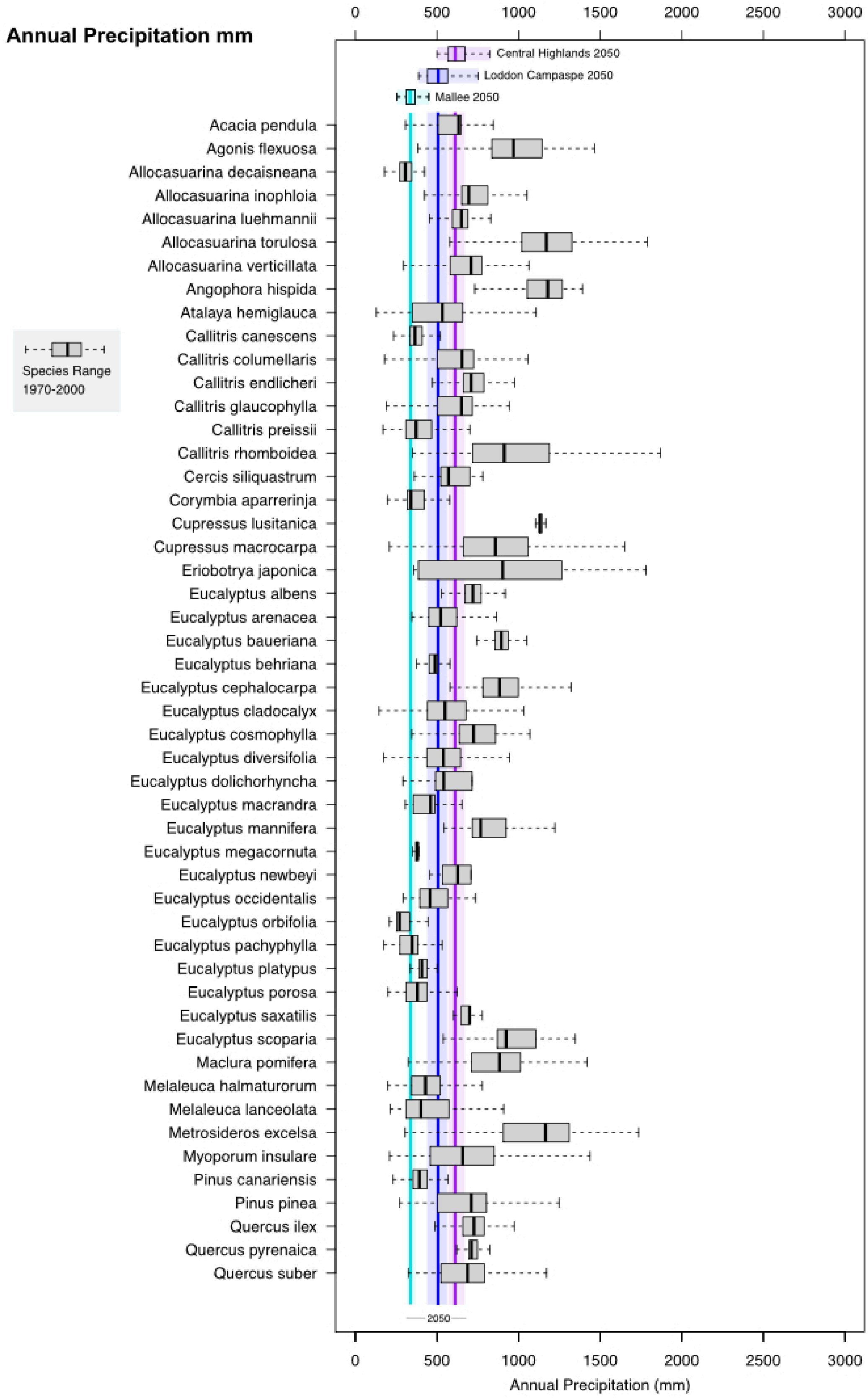


Figure 8 *Boxplots illustrating species ranges for mean annual temperature (°C) for 50 tree species on* ***experimental list****, relative to projected climatic range in each region (Central Highlands purple, Loddon-Campaspe blue, Mallee aqua).*

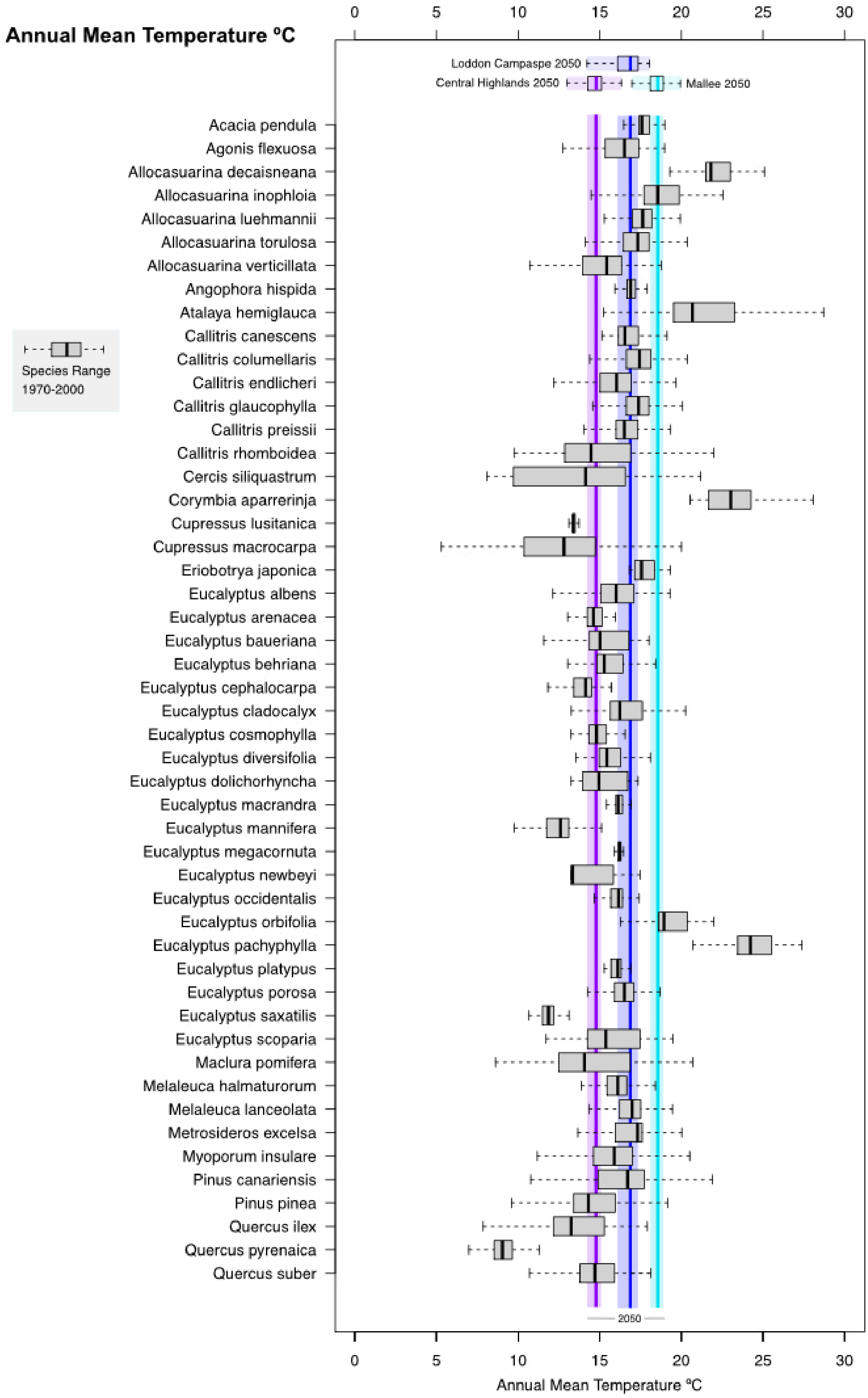
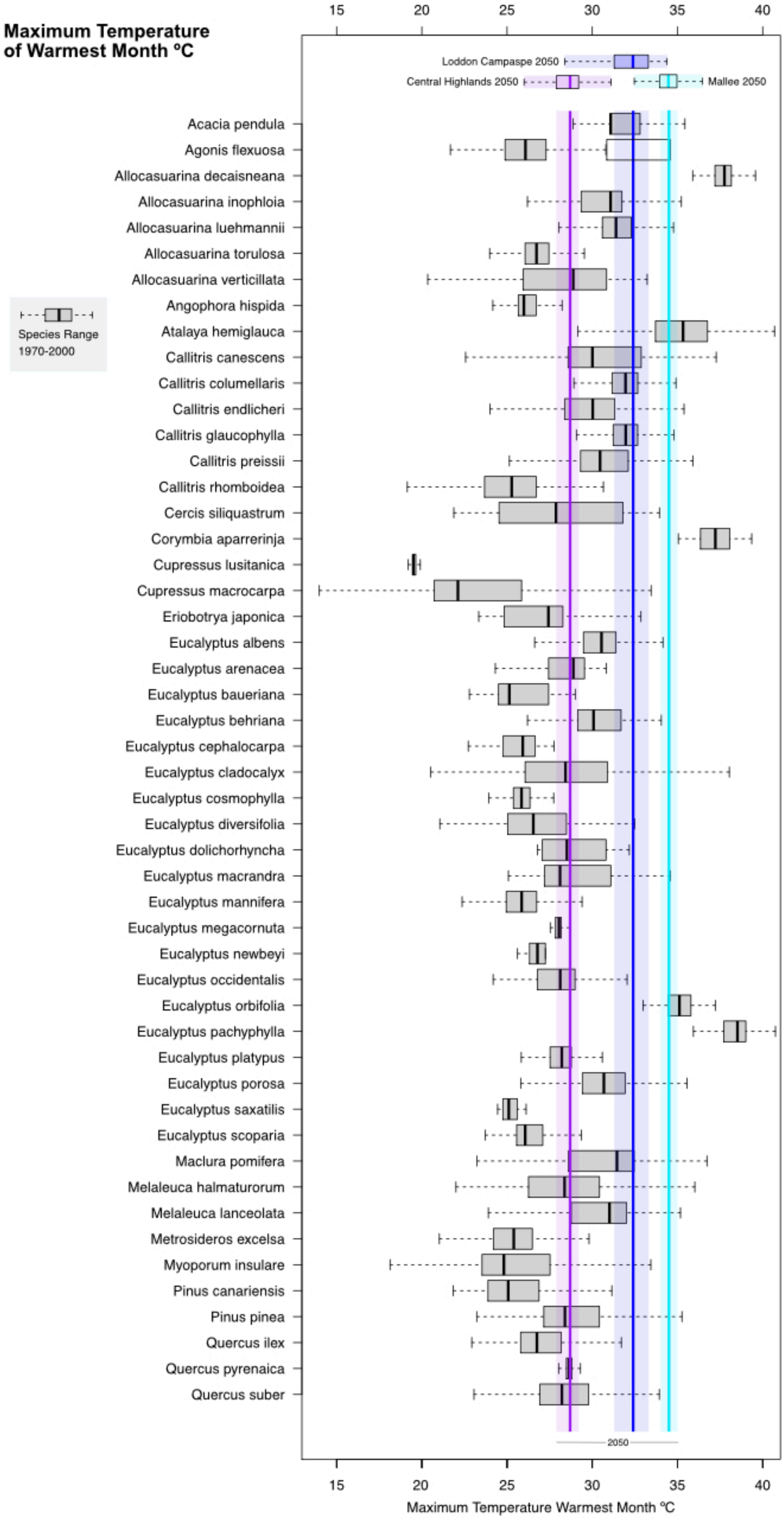


*Figure 9 Boxplots illustrating species ranges for Maximum temperature of warmest month (°C) for 50 tree species on **experimental list**, relative to projected climatic range in each region (Central Highlands purple, Loddon-Campaspe blue, Mallee aqua).*



Planting for the future

Select species likely to be resilient to future climate in each region, by referring to appropriate tables above of low vulnerability species for each region. Cross reference these selections against the species boxplots below, to identify how far inside (overlap) or outside (no-overlap) species climatic ranges are from the projected future climate of each region. Also refer to the Species Selection Matrix (supplied) to ensure appropriate selection of species in regard to their environmental tolerances.

Nurse trees through drought years. Unpredictable growing seasons will be a considerable management concern. Therefore, long term planning of water storage, irrigation and appropriate fertilizing will be key.

Incorporate water sensitive urban design. Explore opportunities for stormwater harvesting and storage to irrigate street trees; use permeable paving; maximise nature strips not concrete to maximise water infiltration and storage deep in the soil.

Use best horticultural practice. Several environmental stressors such as drought, severe temperatures, and insect and pest attack can lead to reduced photosynthesis and growth. This will become more common as climate change intensifies. To give trees best chance of survival and providing best canopy shade, source high quality tree stock that meets the Australian Standard AS 2303:2018 Tree stock for landscape https://www.westernsydney.edu.au/hie/topics/tree_stock_standard. Use mulch, appropriate fertiliser and irrigation as required and ensure soil health is retained and improved.

Generate community support by demonstrating significant savings in the form of carbon storage, reduced power use for cooling, removal of pollutants and property values. Using iTree, McPherson et al. (2016) found that for every dollar spent on trees in California, $5.82 was returned in these annual services. **Estimate your planting costs** using the free Tree Costing Tool that runs in Excel: https://www.horticulture.com.au/growers/help-your-business-grow/research-reports-publications-fact-sheets-and-more/tree-costing-tool-and-instruction-manual/

Create opportunities for positive social and community education by promoting benefits of plantings – explaining tree uses and benefits.

Employ real-time climatic data to help take preventative action. Methods might include using sensors and dataloggers to understand stressors; using BoM weather predictions to make near-term decisions about watering, pruning etc.

Establish trials and monitoring of species performance. This will need to be done to evaluate how new species will perform in cultivation. Implement data collection of key variables with the establishment of new plantings; use drone and remote imaging to understand species performance under different climatic conditions.

Create open data tree inventories. Councils should strongly consider collecting tree inventory data and publishing the data as open source data. Open source data facilitates data sharing, speeds up solutions and enables community engagement.

An excellent guide to publishing council open source data can be found at *Open Council Data: Tools and guidance for local government* (https://opencouncildata.org/). Some Victorian councils have published open source datasets, providing an opportunity to learn from their experience and knowledge.

Examples of current tree inventories for Victoria can be viewed at websites such as *OpenTrees* (http://www.opentrees.org/) and the *City of Melbourne Urban Forest Visual* (http://melbourneurbanforestvisual.com.au/). These data can be downloaded as a comma separated files (.csv) and used as a template for council tree data collection.

Use Hedging, Pleaching or Coppicing. Experiment with pruning to create lateral growth to increase area shaded. Large, lateral branches have lots of strong, compression wood and don't have deep forks where moisture and disease can enter the tree.

Design Multistory canopies to create deep shade' During drought, leaves close their stomata and transpiration declines. This means that there is shade, but the cooling effect is lower because trees are not humidifying the local microclimate. Drought-stressed trees also drop leaves, leading to sparser canopy cover. Drought-adapted trees typically have small, narrow and/ or hanging leaves – meaning their canopy does not create deep shade. So, ideally we need to find large-leaved, drought tolerant trees or come up with planting designs that create deep shade.

To create deeper shade with drought tolerant trees we need to come up with planting designs that are vertically layered. Large and small trees can be used to create a forest canopy. This gives the feeling of protection and when trees are large, wonder.

Broaden species selection to increase diversity of plantings and reduce their vulnerability to future climate, extreme events, pests and diseases. Achieve this by:

- Accepting "messy" species and employing street cleaners or supporting community volunteers to keep urban areas under trees clean and welcoming. This will provide social cohesion benefits as these people can becoming advocates of the planting approach.
- Tolerating slow-growing species. Plants have different drought tolerances depending on the environment they have evolved in. While drought-tolerant species can grow using low amounts of water, they tend to be slow growing, have smaller leaves and thinner canopies, and because they are water-efficient they do not provide lush, humidifying canopies. Creating plantings that combine fast- and slow-growing species may be a way to allow slow growing trees to establish and develop into shade trees.
- Prioritising mixed, complementary plantings that could highlight different seasons, plant forms etc.
- Embracing within-species genetic diversity, rather than uniform plants that are genetic clones.
- Educating the community about the value of planting diversity for future climate resilience to shift mindsets prevalent in planting design and landscape architecture that value uniform, monoculture street tree.

Green infrastructure and ecosystem services into the future. Green spaces are usually classed as amenities that contribute towards the liveability of a town or city. **Trees create urban oases of cool green.** Irrigated greenery provides spaces for social gathering, areas for eating, meeting, resting etc. These opportunities have social cohesion benefits. Because hydrated trees reduce local temperatures by providing cooling shade, they provide an ecosystem service and can be considered 'green infrastructure'. By providing flood management, water treatment and improved urban climates, trees will be an essential tool in establishing the infrastructure of water sensitive cities. Understanding the functional ecology of tree species will be valuable in designing these systems. More information on the concept and design of water sensitive cities can be found at https://watersensitivecities.org.au/.

Caveats

All recommended species are least vulnerable to future climate in each region. Species rated as having higher vulnerability could still be grown if given appropriate care regimes, particularly irrigation. Further our recommendations are based on regional averages. As can be seen in **Figure 3** there is wide variation in projected climate across each region. Consideration should be given to regional climate variation as change will be greater in some local areas than other. More amenable microclimates at a local scale will also support more vulnerable species.

Species evaluations based on bioclimatic models have limitations, because a tree species country of origin and current distribution do not always indicate its physiological plasticity and the range of habitats to which it can adapt (McPherson et al, 2018). This limitation is illustrated in Roloff et al (2009) whose analysis revealed that although honey locust' (*Gleditsia tricanthos*) native habitat is moist bottomlands, it has proven to tolerate very hot and dry situations.

In a similar vein, Kendal et al (2016) found a higher proportion of Australian species compared to exotic species were identified as vulnerable to climate change and therefore not appropriate for planting, because a high proportion of Australian species were identified as having a narrow climate envelope; whereas exotic species had a wide climate envelope. However, this finding may likely to be purely an artefact of a wider global distribution of exotic, horticultural species that have had the long timeframes and broad public interest to be grown in more locations and climates across the world, in contrast to Australian natives and regional endemics that have not had widespread horticultural popularity.

Therefor caution should be applied when evaluating species climatic tolerances from their current climatic ranges. In particular native species that have not been used widely in horticulture, may in reality have much wider tolerances than the plots capture for their native range. Take an experimental approach to these species and try them cautiously in new climates outside their current range.

Using bioclimatic models to predict tree survival in urban environments is complicated by a mismatch between water available to trees urban environments and annual precipitation and the evapotranspiration ratio, due to reduced ground water through impermeable surfaces preventing water infiltration and also due to enhanced ground water from irrigation (Huber et al 2015).

Using the species selection matrix

The overarching goal in species selection for the Cool It project, was to optimise tree survival in urban streets and parks across the three participating Victorian regions. We provide a species selection-matrix that scores species (rows) by their attributes (columns).

Importantly, this matrix ranks species that are most likely to survive and persist in the three regions in 2050 under the projected extreme climate scenario (RCP 8.5).

When using the matrix to identify species for planting in each Shire, prioritise selecting species of low vulnerability to future climate in each region (i.e. high ranking). Planting survival is the highest priority. The vulnerability ranking score for each region is based on overlap between modelled mean annual temperature and mean annual precipitation for each region and data on each species climatic range. Species rankings for climate tolerance can be compared to species scores for drought tolerance, also provided in the Selection Matrix, based on literature and species selection databases.

Other primary criteria for species selection should focus on tolerance to environmental conditions at the local scale, for each Council region and street locality. These criteria include environmental tolerance to: cold, waterlogging, soil compaction, light and soil pH. Secondary criteria for species selection should focus on species amenity.

Acknowledgements

Thanks to Warwick Smith, Co-Founder and economist at the Castlemaine Institute and Honorary Fellow at the University of Melbourne, for assistance with data collection on species tolerances and traits.

Thanks to John Clarke, CSIRO, for initial conversations about using downscaled climate projection data.

Council staff were invaluable in preparation of this report, sharing their goals in urban greening for their Shire, their knowledge about planting successes and failures in their region and their thoughts about challenges of competing priorities in urban tree selection for climate resilience.

Appendices

Appendix I

Top 30 species planted across participating Shires

Preferred species and planting likelihood across participating Shires (nb preferred species for Hepburn Shire are unknown). Staff in charge of tree selection from each Shire were asked to rank the likelihood of planting each species on their tree list the next two years (Planting likelihood rankings were: 0=no chance of planting, 1= low chance and 3=high chance of planting). Number of Councils with each species on their planting list are also counted. From these rankings we identified 30 species most likely to be planted in 2020-21 (below)

Species name	Common name	Ararat Rural City	Buloke Shire	Central Goldfields Shire	Gannawarra Shire	Pyranees Shire	Mount Alexander Shire	Macedon Ranges Shire	Planting likelihood	Count of Councils
Acacia melanoxylon	Blackwood						2	2	4	2
Acer rubrum	Autumn Blaze Maple					2		2	4	2
Angophora costata	Rose Apple					2	2		4	2
Banksia marginata	Silver Banksi					2		2	4	2
Brachychiton populneus	Kurrajong			2	1		2	2	7	4
Callistemon citrinus	Lemon Bottlebrush			1			2	2	5	3
Callistemon viminalis	Weeping Bottlebrush		2	1	2	2			7	4
Celtis australis	European Nettle Tree						2	2	4	2
Corymbia ficifolia	Red Flowering Gum	0	3		2	2		2	9	4
Eucalyptus leucoxylon	Yellow Gum			1	1	2	2	2	8	5
Eucalyptus melliodora	Yellow Box				2		1	2	5	3
Fraxinus angustifolia subsp. oxycarpa	Claret Ash		0		1	2	2	2	7	4
Fraxinus excelsior	Golden Ash					2	2		4	2
Fraxinus pennsylvanica	Green Ash				2			2	4	2
Geijera parviflora	Wilga						2	2	4	2
Gleditsia triacanthos	Honey Locust	3						2	5	2
Hakea laurina	Pincushion Hakea	2				2			4	2
Jacaranda mimosifolia	Jacaranda		2	0	2				4	2
Koelreuteria paniculata	Golden Rain Tree						2	2	4	2
Lagerstroemia indica	Crepe Myrtle	2	3		2	3	2		12	5
Malus ioensis	Prairie Crabapple						2	2	4	2
Melaleuca linariifolia	Flaxleaf Paperbark		2	2					4	2
Melia azedarach	White Cedar		0	0			2	2	4	2
Pistacia chinensis	Chinese Pisctachio						2	2	4	2
Prunus cerasifera	Myobalan Plum	3		1			1		5	3
Pyrus calleryana	Callery Pear	3	3	3	1		3	2	15	6
Quercus coccinea	Scarlet Oak				2	3			5	2
Quercus palustris	Pin Oak			2		3	2	2	9	4
Ulmus parvifolia	Chinese Elm			3			2	2	7	3
Zelkova serrata	Japanese Elm	1		1		2			4	3

Appendix II

Sources of data on species tolerances & attributes

Data source type	Title
Database	*Arid zone Trees.* 2000-2020. www.aridzonetrees.com/
	Atlas of Living Australia. 2020. https://www.ala.org.au/
	Burnley Plant Guide. 2012. University of Melbourne. https://www.bpg.unimelb.edu.au
	CiTree database. 2015. TU Dresden. http://citree.ddns.net/index.php
	Growing Native Plants. 2012 Australian National Botanic Gardens and Centre for Australian National Biodiversity Research, Canberra. https://www.anbg.gov.au/gnp/index.html
	Plant selector+. 2020. Botanic Gardens SA. http://plantselector.botanicgardens.sa.gov.au/home.aspx
	PLANTS Database. 2020. United States Department of Agriculture. http://plants.usda.gov
	Plants For A Future. 2021. http://pfaf.org/
	SelecTree: A Tree Selection Guide. 1995-2021. https://selectree.calpoly.edu/
	TRY – Plant Trait Database. 2020. http://www.try-db.org
	Woody Plants Database. 2018. http://woodyplants.cals.cornell.edu/home
Books & papers	Brune. 2016 Urban trees under climate change. Potential impacts of dry spells and heat waves in three German regions in the 2050s. Report 24. Climate Service Center Germany, Hamburg
	Peate, Macdonald & Talbot. 2006. Grow what Where. Bloomings Books, Melbourne
	Bassuk et al. 2009. Recommended Urban Trees: site assessment and tree selection for stress tolerance
	Forrest. 2006. Landscape trees and shrubs; selection, use and management. Athenaeum Press, Gateshead
	McPherson et al 2018. Shade factors for 149 taxa of in-leaf urban trees in the USA. Urban Forestry & Urban Greening. 31:204-211
	Dubbo Regional Council. Dubbo Street Tree Masterplan
	Flemings Nurseries Pty. Ltd. 2012. Flemings Urban Tree Guide. Flemings Nurseries, Monbulk

Appendix III

Future refinement of species selection methods

With further resources, species selection could continue to be improved and revised to consider priorities of stakeholders, species traits and uncertainty.

- Broaden list of experimental species, particularly for the Mallee region, which is faves the greatest climatic constraints on tree survival in the future. We currently have a list of 770 species that could be explored.
- Extend data collection from the literature, quantifying environmental tolerances and canopy shade attributes for each species. Weight species scores by uncertainty of the data by estimating the degree of uncertainty around each score based on the number of data sources, rigour of the assessment (opinion vs experiment) and whether data was pertinent to species and the Cool It planting regions in question. Taking these lines of evidence into account, uncertainty could be assigned on a scale from 1-3, with higher values indicating lower uncertainty (e.g. Park et al 2018).
- Improve species selection for each Shire by weighting species attributes by their importance to participating stakeholders (e.g. Parsa et al 2019). Also could Classify species functional groups characterised by cooling and amenity attributes, environmental tolerances and vulnerability to future climatic extremes; then match groups to regions or uses (e.g. Park et al 2018).
- Characterise environmental and urban attributes across localities in the Central Victoria and use this to compare tree suitability for different sites (Huber et al 2015). Relevant attributes include: Flood zone, Hardiness zone, Mean Summer Surface Temperature, Soil Texture, soil pH.