Project Name:

Urban Forest Tree Species Research for the ACT

Contracted Entity:

The Australian National University

Client:

Environment, Planning and Sustainable Development Directorate (EPSDD)

ACT Government — Environment, Planning and Sustainable Development Directorate - Environment

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ANU College of Science

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1. Executive Summary

Urban forests enhance urban environments. Urban tree and forests provide a wide range of services that mitigate the urban heat island effect and create more hospitable urban environments. Climate change projections for Canberra, such as NARCliM and CSIRO Analogue, suggest temperatures could increase between 2°C and 4°C by 2090. This will intensify the urban heat island effect and have a significant effect on the health and resilience of trees in the urban forest of Canberra.

Using climate change models and species specific data, this report reviews the Transport Canberra and City Services (TCCS) Municipal Infrastructure Standard (MIS) 25 to determine which tree species are suitable (will survive and thrive) in Canberra's climate change future (2030, 2070 and 2090). The MIS 25 lists a wide variety of tree species with a diversity of traits and characteristics. This report ranks the MIS 25 species according to their climate suitability, capacity as a street trees and advises which particular species that are more suitable in certain scenarios.

Due to concerns with potential allergen, *Platanus orientalis* (and its varieties), *Betula pendula* (and its varieties) and *Juglans nigra* should be classified as a special plant and planted sparingly. This is unfortunate as *Platanus orientalis* is planted widely in Canberra and is very suitable for Canberra's climate change future. It is also a very well renowned urban tree globally. *Betula pendula* and *Juglans nigra* are less suitable and are not widely planted in Canberra.

A number of councils and the National Arboretum Canberra were consulted to discuss potential additions to the MIS 25 species list. The most suitable suggestions include: *Corymbia citriodora*, *Corymbia maculata*, *Cupaniopsis anacardioides*, *Lophostemon confertus*, *Geijera parviflora*, *Grevillea robusta*, and *Albizia julibrissin*.

Growing trees in urban environments is about more than just species selection. In an increasingly challenging urban landscape, planning and infrastructure must support these carefully selected trees species to ensure they have the adequate resources (water and soil) and hospitable growing conditions in order to survive and thrive and provide the services they are intended. This report outlines a variety of strategies to improve the relationship between urban infrastructure and urban trees.

2. Context

Urban forests are increasingly important forms of urban living infrastructure as urban population densities increase and environmental conditions within urban areas become harsher. They serve many functions, many of which are not easily visible or quantifiable (Figure 1). However, while heat-island effects (Figure 2) and increasing extremes in temperature and rainfall are making the ameliorative effects of urban living more important, they simultaneously make establishment and maintenance more difficult. Furthermore, current and projected climate change threatens the longevity of established living infrastructure (e.g. Kendal et al 2017).

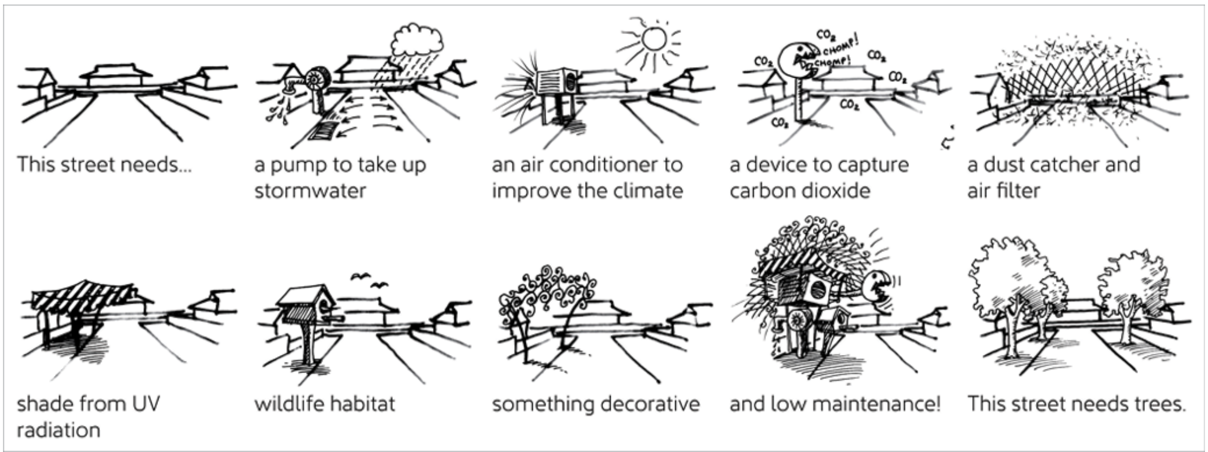

Figure 1: Humorous illustration of the functions that trees provide in urban landscapes (Yourhome, 2013)

Canberra's urban forest is a cornerstone of maintaining Canberra's aesthetic, biological and environmental assets. As living infrastructure, the urban forest also presents substantial ongoing planning and management challenges. The ACT Climate Change Adaptation Strategy - Living with a Warming Climate (EPSDD, 2016) calls for delivery of a 'Living Infrastructure Plan' as part of land sector actions to meet a net zero emissions goal.

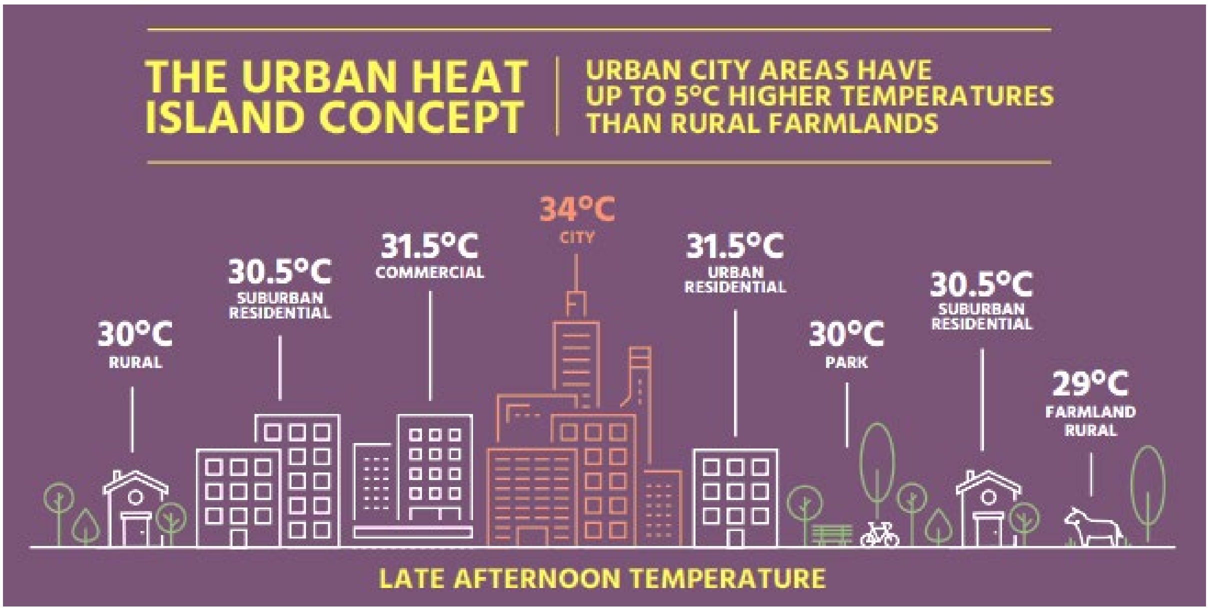

Figure 2: The Urban Heat Island Concept – urban city areas have up to 5 degrees C higher temperatures than rural farmlands. (OCSE, 2017)

Collaborative action between Environment, Planning and Sustainable Development Directorate (EPSDD) and Transport Canberra and City Services (TCCS) has identified that research is necessary to determine which tree species will survive and thrive and continue to deliver the suite of services currently provided by Canberra's urban forests. Specifically, the current list of tree species used on public land needs immediate review to assess its capacity to meet projected future climate variability and extremes. That is, changes in ACT's climate may mean that species currently used in Canberra may either not survive or continue providing ecological, aesthetic and other amenity benefits. Furthermore, species not previously used in the ACT may provide opportunities to maintain or increase the palette of planting options.

Trees provide different services and are at different levels of risk throughout their stages of maturity. Thus, it is important that a diversity of trees, both in age/maturity and species, be maintained across Canberra's metropolitan areas (Districts) to promote resilience to climate variability and resistance to insect pests and disease vectors.

This report aims to contribute to informed decision making on the selection of tree species for the ACT. The recommendations draw upon current TCCS species lists; detailed examination of species-level traits; definition of healthy tree criteria; qualitative evaluation against current hypotheses of drought-induced mortality; safe usable life expectancies; and, climate change projections for Canberra.

3. Consultancy Brief

This report reviews the Transport Canberra and City Services Municipal Infrastructure Standard, part 25 (TCCS MIS 25), which provides details of suitable plant species, for urban landscapes such as municipal streets and open spaces on unleased territory land in the ACT.

The review was undertaken to identify tree species suitable (survive and thrive) for Canberra's projected future (2050, 2070, and 2090) climates and maximise summer-time cooling effect of Canberra's urban areas.

Three deliverables from the review were identified:

1. Advise on the most suitable ('top 10') commercially available tree species suitable for current and future planting, for effective maximum summertime cooling in town and group centres, that are appropriate for:
    - High pedestrian traffic pavements with strata cells;
    - Low pedestrian traffic dryland grass or gravel, and;
    - Irrigated grass conditions.
2. Advise on tree species that would be suitable for Canberra's projected future climates (2050, 2070, and 2090) that are not currently readily available or grown in Canberra, but could be grown.
3. Advise on the 'top ten' currently commercially available tree species suitable today and in future, effective for maximum summertime cooling, that are appropriate for:
    - Lanes and narrow verges
    - Local and collector streets
    - Avenues and arterial roads.

4. Methodological background

This report draws together current knowledge of urban tree services, and theory on tree decline to generate a multi-criteria matrix for urban tree selection in the ACT. A brief summary follows to provide a methodological basis for subsequent analyses.

4.1. Urban forests and tree health

Urban forests deliver a suite of values in urban environments, ranging from amelioration of environmental extremes to improving human well-being. Maintaining tree health is critical for ensuring trees successfully function as components of an urban forests. Healthy trees maintain full living crowns, resist biotic pests and have the capacity to adapt to environmental variability while continuing to grow at an appropriate rate. Among the outcomes of these attributes of healthy trees is the delivery of key urban services including rain interception and storm-water mitigation, pollution interception, shading and cooling, habitat provision and pleasing aesthetic outcomes, as well as less tangible human psychological benefits.

Urban environments present substantial challenges that impact significantly upon tree health and changes to a tree's planted environment can significantly impact upon health outcomes. For example, modifications of tree root zones during urban redevelopment can dramatically alter both water availability within the soil as well as the balance of water-harvesting and water-using plant components and lead to declining tree health. Similarly, changes in the climate a tree experiences, through increase heat-island effects or progressive changes in rainfall and temperature regimes associated with regional climate variability, may also negatively impact upon tree health. From this perspective, projected changes in climate in response to rising atmospheric CO_2 concentrations presents significant challenges for urban trees. That is, the interactive effects of ongoing physical and climatological change in urban tree environments may lead to large-scale tree and urban forest failure. In south-east Australian cities, the combination of heat output from built infrastructure and climate-change related variability in rainfall and temperature regimes mean that tree decline associated with increasing urban drought severity and frequency is a principal concern for urban tree managers.

4.2. Urban drought and tree decline

Water availability is one of the most important and limiting factors for tree growth and health (Clark and Kjelgren, 1990). While droughts have been implicated in the increasing decline of trees and forests worldwide, a question that confronts tree managers, especially those within urban environments, is why some trees survive and others die as a consequence of drought. This question can only be understood in the context of physiological mechanisms.

Two mechanisms – hydraulic failure and carbon starvation – are posited as the basis of drought-related tree decline (McDowell et.al. 2008) (Figure 3). Hydraulic failure occurs when drought intensity is sufficient to lead to the acute loss of water potential and vascular failure via the formation of embolisms. The role of hydraulic failure in the decline natural and planted forests remains unclear. Nevertheless, it is clear that individual plants, and parts thereof, are highly susceptible to hydraulic failure when evapotranspiration is high and soil water availability is acutely low such as during extreme summer heatwaves.

Carbon starvation occurs when prolonged drought – even of moderate intensity – significantly reduces long-term plant-level photosynthate supply. That is, by failing to offset ongoing respiratory losses, assimilation of carbon is insufficient to meet ongoing plant functional requirements. While drought-induced carbon starvation can theoretically lead to tree death, loss of plant vigour and its associated consequences, such as increasing susceptibility to biotic attack, often accelerate the process and may present as proximal causes of tree decline.

The susceptibility of individual species and plants to either hydraulic failure or Carbon starvation underpins interspecific differences in response to drought. However, the importance of both mechanisms depends upon a specimen's growing environment and urban environments greatly promote their drivers.

In urban environments, the availability of water is negatively impacted upon by impermeable built urban infrastructure. These impermeable surfaces can create or intensify drought conditions simply through preventing infiltration of rainfall and increasing surface run-off (Figure 4). In addition, through vastly reducing total evapotranspiration, urban infrastructure increases vapour pressure deficit – the difference between the saturation of the leaf and ambient environment – significantly increasing plant water use, intensifying urban heat and increasing water loss from the remaining vegetation. Each of these factors may contribute to increasing frequency, duration and severity of drought experienced in urban environments.

4.3. Safe useful life expectancy

While trees are established in urban areas to provide a suite of services, the provision of these services varies throughout a specimen's life. The provision of canopy-related services, for example, generally increases as a tree ages and its canopy expands. Conversely, the decline of canopy cover in response to declining vigour and accumulation of physical injuries may also reduce service delivery as age increases. Viewing urban trees in the context of the services they delivery effectively shortens the realisable life span of urban trees and contributes to their reduced life spans relative to those found in natural habitats (City of Melbourne, 2011). The longevity of trees is further limited by their safe useful life expectancy in urban environments. That life expectancy may be quantified as the age at which the cost of maintenance and risk of injury exceeds at tree's service value (Brack, 2016).

While projections of safe useable life expectancy have been used to guide urban tree planning, those projections assume the site conditions remain unchanged (Barrell, 1993). Clearly, anticipated changes in climate violate this assumption and impact upon projected safe useable life expectancies. Shortened life expectancies might be anticipated where climate change is expected to lead to increased risk of hydraulic failure and Carbon starvation as a consequence of drought duration, frequency and severity as well as heat stress.

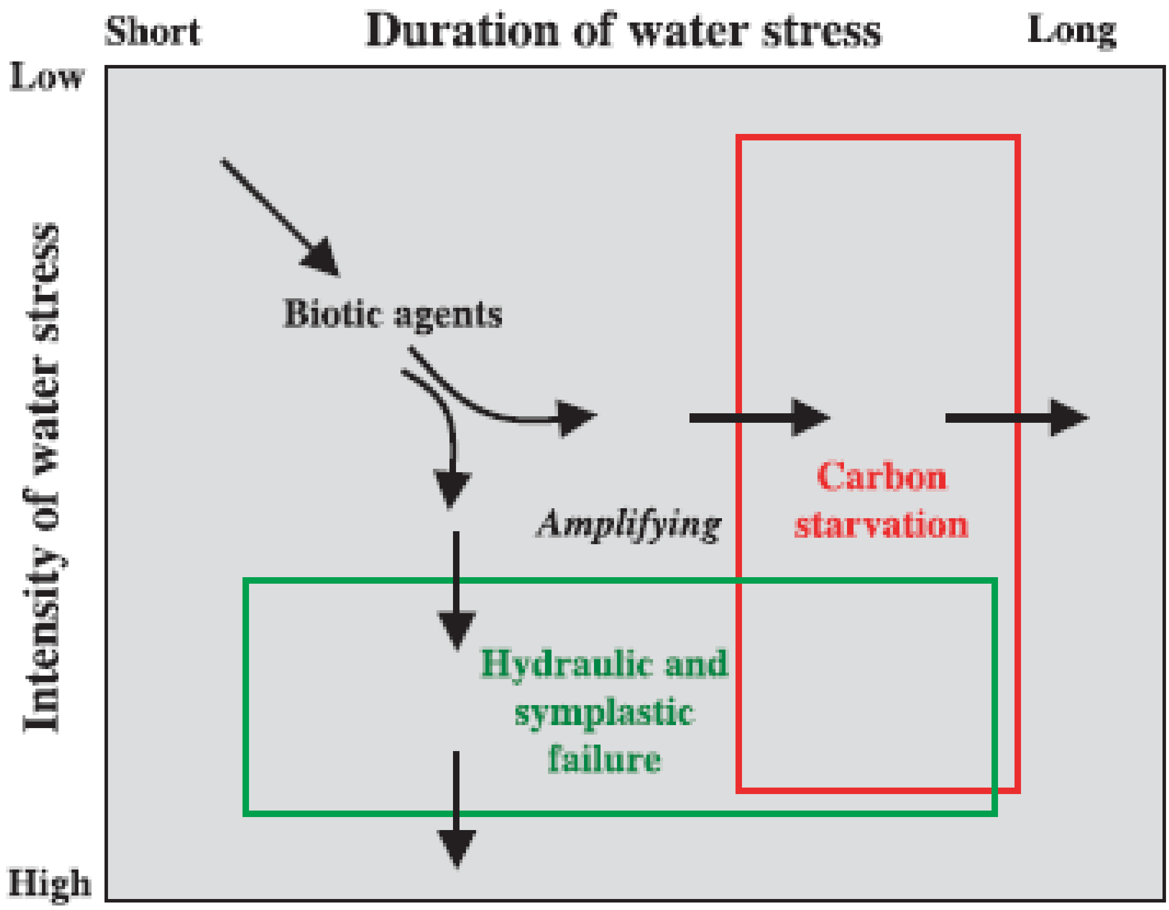

Figure 3: Theoretical relationship between the temporal length of drought (duration), the relative decrease in water availability (intensity), and the two hypothesized mechanisms underlying tree mortality. During short intense water stress events hydraulic failure (acute loss of water potential and vascular failure) can occur, while long slow water stress events can cause Carbon starvation (long term lack of photosynthate supply). Both processes increase a plants susceptibility to biotic agents (pests and pathogens) which often accelerate the process (McDowell et.al. 2008, p. 722, Figure 3).

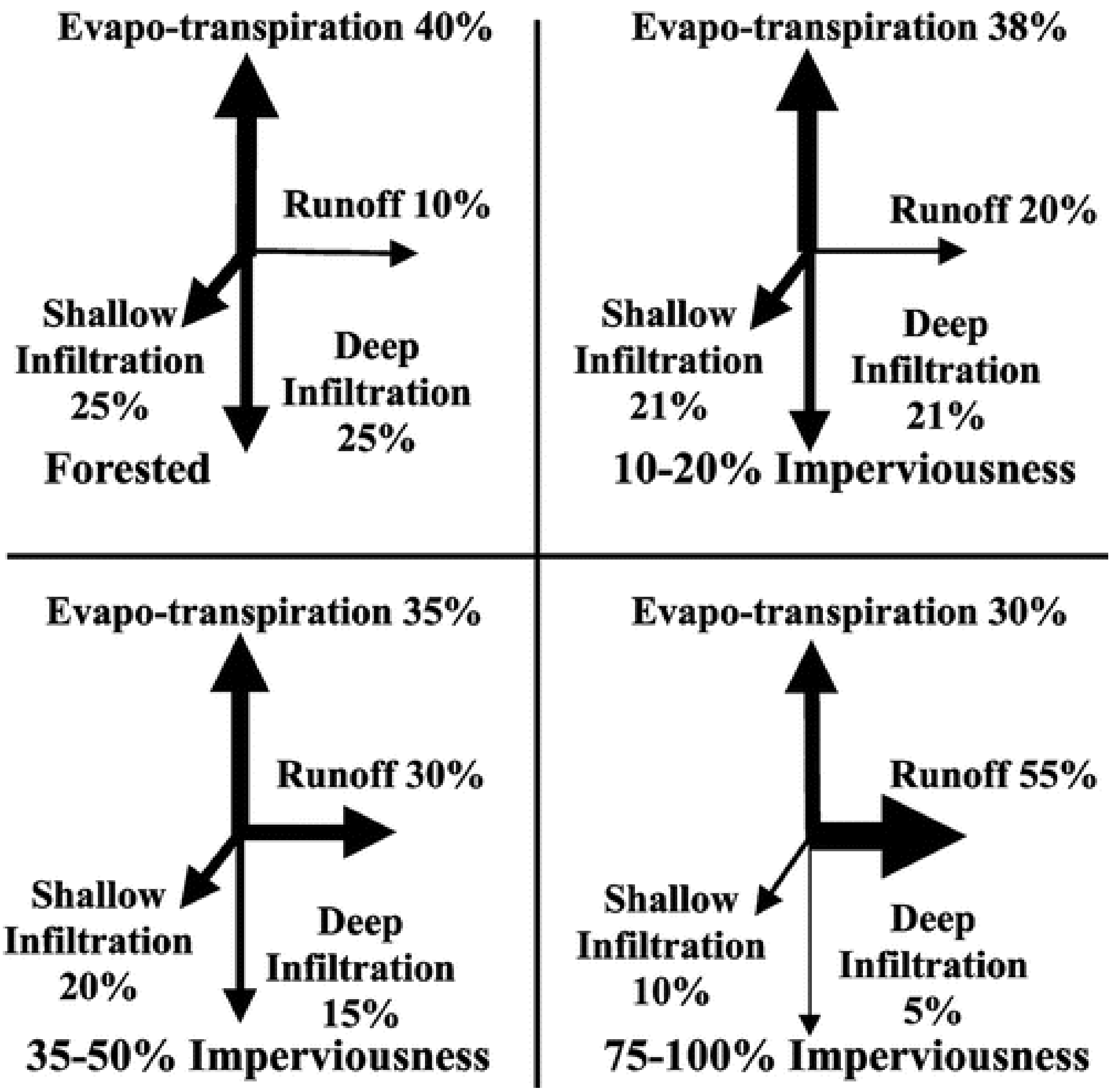

Figure 4: Changes in hydrological flow with increasing impervious surface cover in urbanising catchments. In forested landscapes there are no impervious barriers. Infiltration is high and runoff is low. As imperviousness increases, less water is able to infiltrate resulting in increased runoff, less soil moisture and reduced evapotranspiration (Arnold and Gibbons, 1996; as modified by Paul and Meyer, 2008, p. 339, Figure 1).

5. Method

In the review outlined in this report, projected climate changes and current natural and planting distributions will be used to assess each species' likely ability to survive changing climate. These assessments used summaries of the climate envelope associated with the planted and natural distribution of species listed within the TCCS MIS 25 and regional climate projections and species-level traits to develop a multi-criteria selection matrix.

5.1. TCCS MIS 25

The Transport Canberra and City Services Municipal Infrastructure Standard, part 25 (TCCS MIS 25), provides details of suitable plant species for urban landscapes such as municipal streets and open spaces on unleased territory land in the ACT.

Species within the TCCS MIS 25 are currently assessed against a suite of environmental (climate; drought; geology; drainage and soils; topography and frost) criteria, biotic plant-level traits (longevity, pest plant status and weed potential, pest and disease vulnerability) as well as management considerations (unsuitable properties). The species are also categorised by height. These criteria are intended to be readily applied to determine tree species are suitability for Canberra's urban forest plantings on public land.

The TCCS MIS 25 consists of 211 individual species, of which 145 are internationally introduced species and 66 are Australian native species. The TCCS MIS 25 comprises 50 genera, of which *Eucalyptus* (43 species) is most commonly represented followed by *Quercus* (20 spp.), *Prunus* (15 spp.), *Acer* (11 spp), and *Fraxinus* (10 spp). Deciduous trees species comprise 56% (120) of species within the TCCS MIS 25 and all Australian natives in the standard are evergreen, with exception to Melia azedarach. Most (200) of the species listed within the TCCS MIS 25 are commercially available.

The TCCS MIS 25 was developed in 2002 by Transport and Municipal Service (TAMS) now Transport Canberra and City Services (TCCS). The document has been reviewed 4 times and is currently in its fifth review. TCCS supplied the most up to date version of the document at the commencement of the project.

A range of tree and urban forest assessment tools[1][2][3][4][5] were reviewed to ensure the criteria in the MIS 25 and the multi-criteria matrix were sufficient for scoring and assessing tree species suitability to Canberra's climate change future. The MIS 25 and criteria matrix we found be sufficient.

5.2. Species-level multi-criteria matrix

A multi-criteria matrix was used to quantify species included in the TCCS MIS 25. These criteria were subsequently used to assess species according to their suitability and vulnerability to Canberra's future climate across a number of scenarios. Criteria were principally derived from the TCCS MIS 25 selection matrix. Criteria within that matrix that reflected more than one species trait were disaggregated into multiple criteria.

Either core selection criteria were used to quantify species ability to survive and thrive. These were drought tolerance; frost tolerance; extreme heat tolerance; shade type and density; allergen potential; weed potential; longevity, and irrigation requirements. Temperature increase vulnerability was initially chosen as a core criteria, however on acquiring the data, it was found that not all species in the MIS were analysed. Therefore it could not be used to score and ranks the species.

Each tree received a score of 1-5 for each criterion, where 1 was the poorest outcome and 5 the best. Scores were summed to produce a species-level score, allowing each species to be ranked according for all criteria. Additional criteria, including crown width; compatibility with asset protection zone and available soil volume were used to filter tree species for the different scenarios (see section 5.5
Scenario assumptions).

A second ranking method was also applied, which included weighting of climate-related criteria. The climate-related criteria were doubled to reflect the importance of these criteria for species survivability in Canberra's climate change future.

Species-level data was compiled from sources including commercial nursery websites; local and international botanic garden and herbarium websites; TCCS and local Council factsheets

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[1] i-Tree www.itreetools.org
[2] SITES www.usgbc.org/resources/sites-rating-system-and-scorecard
[3] Infrastructure Council of Australia (ISCA) tool v2018 https://isca.org.au/component/content/article?id=856
[4] System of Environmental-Economic Accounting (SEEA) https://seea.un.org
[5] Urban Forest Diversity Guidelines - 2011 Tree Species Selection Strategy for the City of Melbourne - https://www.melbourne.vic.gov.au/SiteCollectionDocuments/urban-forest-diversity-guidelines.pdf

and databases; local and international Government department websites; University and research centre websites; International Union for the Conservation of Nature (IUCN); Wikipedia; Atlas of Living Australia (ALA); Global Biodiversity Information Facility (GBIF) and active discussions with researchers from The Australian National University (ANU) and The University of Tasmania (UTas) (see Appendix 1).

5.3. Description of each Criteria

The following section is a description of the criteria used in the multi-criteria matrix. Table 1 outlines the core and non-core criteria, sources of information and a description of scoring for ranking species' suitability to Canberra's climate change future.

5.3.1. Drought Tolerance

Drought tolerance is defined as the ability of a species to withstand extended dry periods. Generally, plants that require less water (once they are established) are drought tolerant because they are adapted to regions with frequent drought or to soils with low water-holding capacity.

5.3.2. Frost Tolerance

Frost tolerance is the degree to which plants can withstand exposure not only to cold temperatures, but to actual frost. Frost (extracellular) and freezing of plant cells (intracellular) can cause severe damage to the entire plant or small parts of plant tissue reducing.

5.3.3. Extreme Heat Tolerance

Extreme heat tolerance is defined as the ability of a species to live, thrive and withstand in locations that can experience very high (extreme) temperatures. Different species have varying responses/adaptations to extreme heat and temperature beyond a threshold level for a period of time can cause irreversible damage to plant growth and development. Some species have excellent stomatal control, others shut down photosynthesis while some increase respiration to cool their leaves.

There is very limited species level data on extreme heat tolerance. As a result, extreme heat tolerance was determined by examining species distribution (GBIF Database) and recording the highest temperatures across this distribution. The multi-criteria score was then delineated based on the mean of the highest temperature across a species' distribution. For each degrees above the Canberra record maximum temperature (42.2°C (BOM 2018d)) the species score was increased 1 point up to a maximum of 5.

5.3.4. Temperature Increase Vulnerability

Temperature increase vulnerability is defined as the vulnerability of a species to increases in mean annual temperature. The distribution of a plant species is limited by the range of climatic conditions to which the species can adapt (Criddle et al. 1994), and one of the strongest determinants of geographic distribution of plants is temperature (Woodward and Williams, 1987). Canberra has a temperature envelope, which is projected to get hotter. Plants have temperature tolerance limits (temperature envelope) that reflect adaptation to their native habitats, with temperature extremes defining the geographic limits for plant survival and reproduction (Hatfield and Prueger 2015).

The data used for this criteria uses Canberra current, 2040 using RCP4.5, and 2090 using RCP8.5 temperature envelopes and compares them with the temperature envelope of each species developed by Professor Dave Kendal[6] from the University of Tasmania. The extent of overlap determines the species' vulnerability to temperature increase (Figure 5).

[6] http://www.utas.edu.au/profiles/staff/cose-ted/dave-kendal

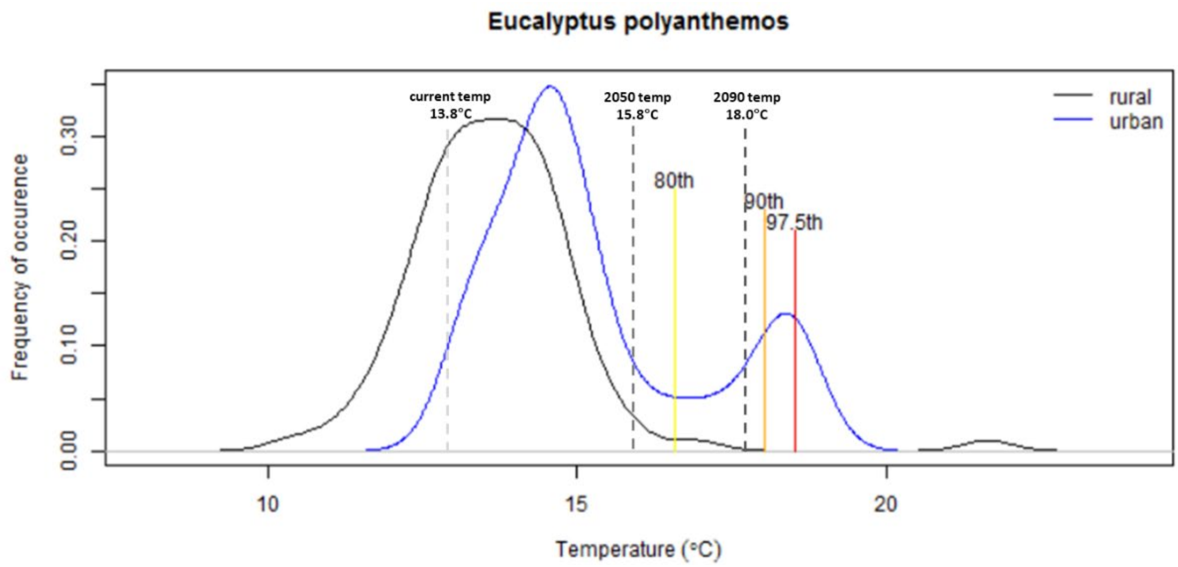

Figure 5: Temperature envelope of Eucalyptus polyanthemos in rural and urban areas. Dashed vertical lines indicate Canberra's average annual temperature across 3 time periods: current, 2050@RCP8.5, and 2090@RCP8.5. Coloured vertical lines indicate threshold percentiles to categorise species temperature vulnerability (Kendal, et al., 2017, p. 5, Figure 5).

A species is characterised as not vulnerable if the temperature of Canberra is similar to more than 80% of locations where the where the species is found. A species is characterised as highly vulnerable when the temperature of Canberra is warmer than 97.5% or more of the locations where the species is found (Figure 6).

Rating	Metric	Description
Green	The temperature is similar to most locations where this species is found (i.e. the temperature is below the 80^{th} percentile)	The species is not considered at risk from increasing temperatures
Yellow	The temperature warmer than most locations where the species occurs (i.e. temperature > 80^{th} percentile)	The species is slightly at risk from increasing temperatures
Orange	The temperature is warmer than 90% of the locations where this species is found (i.e. the temperature > 90^{th} percentile)	The species is moderately at risk from increasing temperatures
Red	The temperature is warmer than 97.5% of the locations where this species is found (i.e. the temperature > 97.5^{th} percentile)	The species is at high risk from increasing temperatures

Figure 6: Temperature risk colour coding scheme (Kendal et. al 2017).

5.3.5. Shade type and density

Shade type and density represents a qualitative estimate of the degree of shade projected by a species. This criteria considers the form of the tree, size of mature tree, and leaf shape and orientation.

5.3.6. Potential Allergen

Potential allergen is defined as the degree of allergic reaction the species can potentially cause. Of the approximately 60,000 tree species, less than 100 have been shown to cause allergies. Most allergies related to the pollen and are species specific and/or related to the male cultivar of a particular species. Allergy information was provided by pollen expert Professor Simon Haberle[7] who is using his knowledge of Australian pollen to explore the impact of atmospheric pollen and spores on respiratory health through his work on the Palaeoworks[8] and Canberra pollen[9,10] websites and AirRater[11] app.

5.3.7. Potential Weed

Potential weed is defined as the degree to which a species could spread in a landscape and the impact (economically, environmentally and socially) that it could potentially have. Weeds have major economic, environmental and social impacts in Australia. They can cause significant damage to natural landscapes, agricultural lands, waterways and coastal areas (Department of Environment, 2018).

5.3.8. Longevity

Expected life span that a tree species can be retained in a safe and aesthetically pleasing manner in the situation (providing site conditions remain unchanged). This is generally named "Useful Life Expectancy (ULE)". Most urban trees have reduced life spans compared to those found in natural habitats. Trees reach their maximum ULE when the cost of maintenance and risk of injury exceeds their value (http://www.anu.edu.au/news/all-news/our-cities-need-more-trees-but-that-means-being-prepared-to-cut-some-down).

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[7] https://researchers.anu.edu.au/researchers/haberle-sg
[8] http://palaeoworks.anu.edu.au/aerobiology.html
[9] http://canberrapollen.com.au/
[10] http://www.abc.net.au/news/2015-10-27/godzilla-hay-fever-season-hits-canberra-as-pollen-count-doubles/6888438
11 http://airrater.org/

5.3.9. Irrigation

Irrigation is defined as the amount of supplementary irrigation a species requires to maintain an appropriate growth rate and grows and performs as a healthy specimen. Supplementary irrigation allows species that suffer adverse effects of soil moisture stress to grow in locations where that would not normally grow.

5.3.10. Width

Width is defined as the width (diameter) of the tree canopy at 20 years old or two-thirds mature canopy width.

5.3.11. Asset Protection Zone

An asset protection zone (APZ) is an area in and/or beside urban development that is designed and managed to reduce the risk of adverse impacts from bushfires on assets (ACTPLA, 2008). These areas generally surround a building or an asset of value whether residential, commercial, industrial or environmental (Bushfire Hazard Solutions, 2017).

Trees are generally permitted in asset protection zones so long as there is a sufficient gap between tree canopies and there is no continuous tree canopy leading from the hazard to the asset (NSWRFS, 2018).

Some tree species are not compatible (not permitted) with asset protection zones as they have physical characteristics, such as highly flammable foliage or bark, which can exacerbate fire behaviour increasing the risk of damage to life and property. Data for this criteria was collected from the Fire Management Guidelines for Land Management Activities, June 2017, ACT Parks and Conservation Service, provided by TCCS.

5.3.12. Available Soil Volume

Available soil volume (ASV) is defined as the minimum underground space to support healthy tree root growth, for healthy trees to grow to their potential (Figure 7). There is a correlation between canopy area and soil volume.

In general, the more soil available to a tree, the healthier it will be and the larger the canopy will be. Available soil volume is suggested to be one of the most limiting factors in the growth and health of urban trees (Kopinga 1991; Craul 1992; Lindsey and Bassuk 1992; Grabosky and Bassuk 1995).

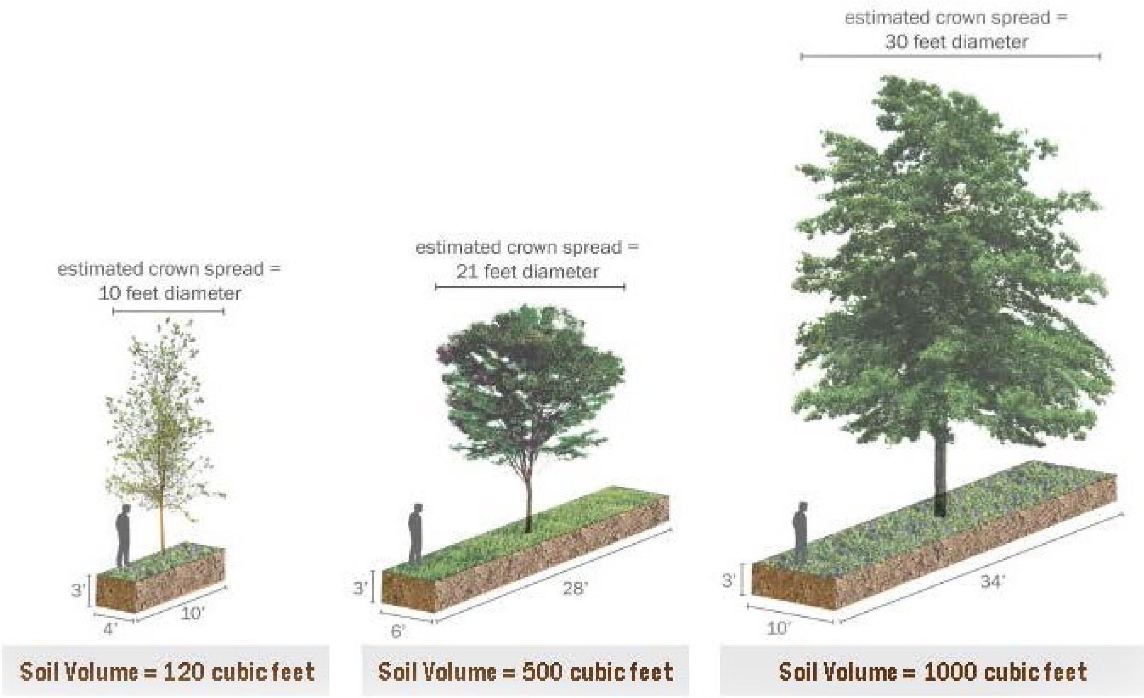


Figure 7: Example of soil volume needed to sustain certain sized trees (Simpson, 2015, Slide 13)

Table 1: Core and non-core criteria, source and scoring description of the multi-criteria matrix for ranking tree species suitability to Canberra's climate futures.

Attributes	Criteria	Source	Scoring
Climate based	*Drought tolerance	TCCS factsheet, Nursery and Botanic garden information.	1 = Very Low tolerance of extended dry periods. 2 = Low tolerance of extended dry periods 3 = Moderate tolerance of extended dry periods 4 = High tolerance of extended dry periods 5 = Very High tolerance of extended dry periods
Climate based	*Frost Tolerance	TCCS factsheet, Nursery and Botanic garden information.	1 = Not tolerant of frost 2 = Low tolerance of frost 3 = Moderate tolerance of frost 4 = High tolerance of frost 5 = Very High tolerance of frost
Climate based	*Extreme heat tolerance	Cross reference the highest record temperatures across the distribution of the species on Global Biodiversity Information Facility (GBIF) and Atlas of Living Australia (ALA).	1 = Not tolerant of extreme heat

Attributes	Criteria	Source	Scoring
			2 = Low tolerance of extreme heat 3 = Moderate tolerance of extreme heat 4 = High tolerance of extreme heat 5 = Very High tolerant of extreme heat N/A = No data is available for this species
Climate based	^Temperature increase vulnerability	Dave Kendal– Senior lecturer in environmental management Geography and Spatial Sciences UTas/UMelb [1]	Red = The species is at high risk from increasing temperatures Orange = The species is moderately at risk from increasing temperatures Yellow = The species is slightly at risk from increasing temperatures Green = The species is not considered at risk from increasing temperatures
Other	*Shade type and density	TCCS factsheet, Nursery and Botanic garden information.	1 = Low shade cast. 2 = Moderate to Low shade cast. 3 = Moderate shade cast. 4 = Moderate to High shade cast. 5 = Heavy shade cast.
Other	*Potential Allergen	Simon Haberle – Senior research fellow & Pollen Expert ANU [2]	1 = High potential as an allergen 2 = Moderate to High potential as an allergen 3 = Moderate potential as an allergen 4 = Low to Moderate potential as an allergen 5 = Low potential as an allergen
Other	*Potential Weed	TCCS factsheet, Nursery and Botanic garden information. Government Websites	1 = High potential weed 3 = Moderate potential weed 5 = Low potential weed
Other	*Longevity	TCCS factsheet, Nursery and Botanic garden information.	1 = Short (<20 years) 2 = Short to Medium 3 = Medium (20-60 years) 4 = Medium to Long 5 = Long (>60 years)
Other	*Irrigation	TCCS factsheet/database, Nursery and Botanic garden information.	1 = High need for Irrigation 3 = Moderate need to Irrigation 5 = Low need for Irrigation

Attributes	Criteria	Source	Scoring
Other	^Width	TCCS factsheet/database, Nursery and Botanic garden information.	0-5m = Narrow
			5-10m = Medium
			10+m = Wide
Other	^Asset Protection Zone	Fire Management Guidelines for Land Management Activities, June 2017, ACT Parks and Conservation Service – Provided by TCCS	Yes = Compatible with Asset Protection Zone
			No = Not Compatible Asset Protection Zone
Other	^Available Soil Volume	TCCS factsheet, Nursery and Botanic garden information.	Not less than "amount" m3

*Core criteria ^Non-core criteria

[1] http://www.utas.edu.au/profiles/staff/cose-ted/dave-kendal

[2] https://researchers.anu.edu.au/researchers/haberle-sg

5.4. Climate Change Projections

This research uses NSW / ACT Regional Climate Modelling (NARCliM) and CSIRO Analogues to project Canberra's climate change future. These projections allow for analysis across a variety of time scales and emission scenarios. Evidence suggests that climate change might be taking place faster than expected and that we have reached 2030 projections already. In addition, it is also difficult to isolate species responses to specific temperature increases across the time periods i.e. how does a tree respond to 0.9°C compared to 2.3°C. As a result, analysis of species suitability to Canberra climate change future is based on the maximum consensus worst-case scenario projections (RCP8.5) projections for the far future times period 2070 (NARCliM) and 2090 (CSIRO Analogue).

5.4.1. NARCliM (NSW / ACT Regional Climate Modelling)

The NARCliM research partnership has used over 100 climate variables to produce a suite of twelve regional climate projections for south-east Australia across the time periods near future 2030 (2020-2039) and far future 2070 (2060 - 2079).

For the ACT, the NARCliM projection (Figure 8) states that:

a. Maximum temperatures are projected to increase in the near future by 0.6 - 0.9°C and 1.4 - 2.3°C in the far future.

b. Minimum temperatures are projected to increase in the near future by 0.4 - 0.7°C and 1.4 – 2.3°C in the far future.

c. The number of hot days (above 35°C) will increase (Table 2).

d. The number of cold nights (below 2°C) will decrease (Table 3).

e. Annual rainfall amount of not projected to change, however rainfall is project to decrease in spring and increase in summer and autumn (Table 4).

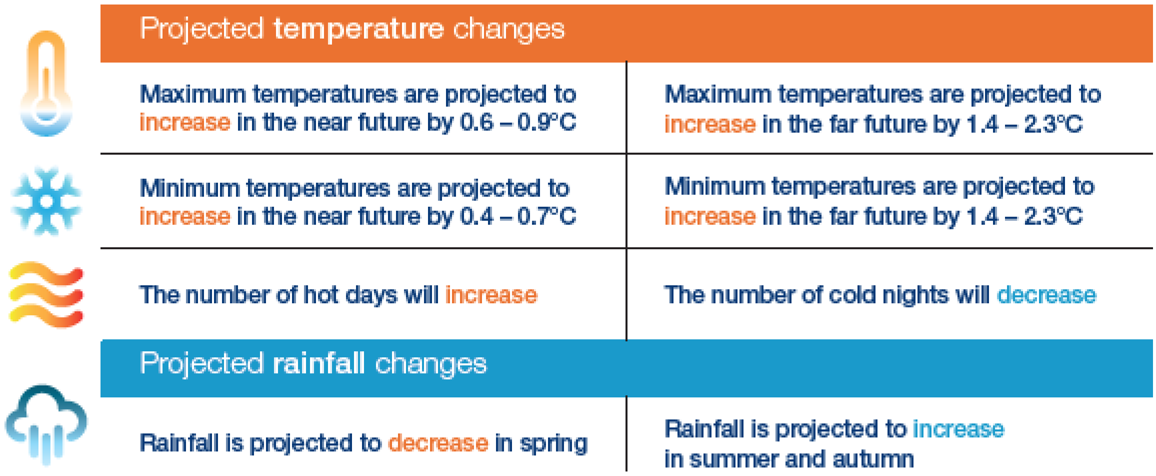


Figure 8: Snapshot of projections for Canberra in the near future (2030) and far future (2070) NARCliM, 2016)

Table 2: Projected change in number of hot days across time periods 2018, 2030 and 2070 (NARCliM, 2016)

Time Period	Number of Hot days (>35°C)	Comment
2018	10	The hotter weather will be mainly in spring and summer but will extend into autumn (ESPDD, 2016)
2030	11-15	
2070	20-30	

Table 3: Projected change in number of cold days across time periods 2018, 2030 and 2070 (NARCliM, 2016)

Time Period	Number of Cold nights (<2°C)	Comment
2018	70-90	A decrease in the number of cold nights is projected for all seasons, dominated by decreases in winter and spring (NARCliM Snapshot, 2016)
2030	57-77	
2070	27-47	

Table 4: Projected rainfall variability across time periods 2018, 2030 and 2070 (NARCliM, 2016)

Season	2030 rainfall variability	2070 rainfall variability	Comment
Summer	-5 to 5%	5 to 20%	Slight/Moderate increase in summer (Dec, Jan, Feb)
Autumn	5 to 10%	5 to 20%	Large increase in autumn (Mar, April, May)
Winter	-5 to 0%	-5 to 0%	Slight decrease in winter (June, July Aug)
Spring	-5 to -10%	-5 to -20%	Large decrease in spring (Sept, Oct, Nov)
Annual	-5 to 0%	-5 to 5%	No significant change projected

Table 5 compares NARCliM with CSIRO Analogues across a number of time periods and emissions scenarios.

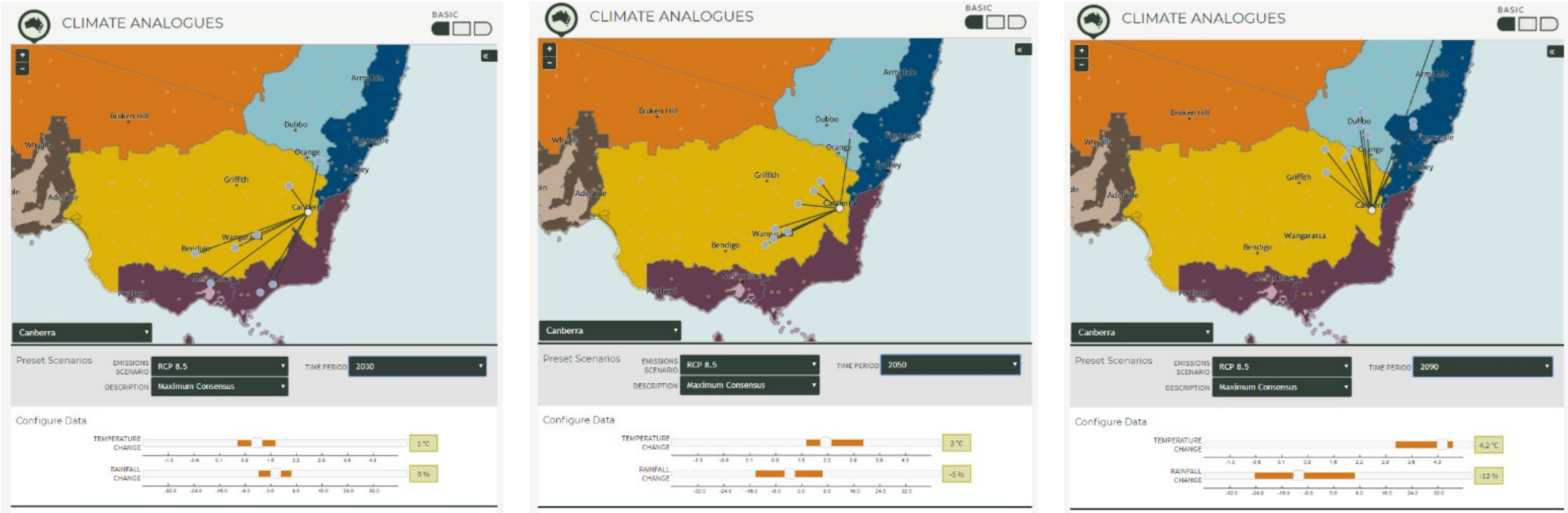
Table 5: NARCliM and CSIRO Climate Analogue projections for temperature and rainfall across four future time periods. (NARCliM, 2016; CSIRO, 2016)

	2030		2050		2070		2090	
	Temp Change	*Rainfall Change*	*Temp Change*	*Rainfall Change*	*Temp Change*	*Rainfall Change*	*Temp Change*	*Rainfall Change*
NARCliM	0.9°C	0%	-	-	2°C	0%	-	-
CSIRO Climate Analogues – RCP 4.5 Max. consensus	0.9°C	0%	1.2°C	1%	-	-	2°C	-4%
CSIRO Climate Analogues – RCP 8.5 Max. Consensus	1.0°C	0%	2.0°C	-5%	-	-	4.2°C	-12%

5.4.2. CSIRO Climate Analogues

The CSIRO climate analogues tool the uses emission scenario models of temperature and annual average rainfall to proposed the future climate (2030, 2050, 2090) of a location of interest (in this case Canberra) and matches it with the current climate of another location. For instance, Canberra's future climate in 2090 will be like the current climate of Dubbo, NSW (Figure 9).

Although the tool does not take into account other factors such as frost, soil types, solar radiation and other local climatic influences, it is a useful tool to spatially conceptualise, visualise and communicate how Canberra's climate is may be in the future.



Location: Canberra
Emissions Scenario: RCP 8.5
Time Period: 2030
Model Description: Maximum Consensus
Analogue Towns:
Bairnsdale, Bathurst, Benalla,
Albury-Wodonga, Sale,
Bendigo, Young,

Location: Canberra
Emissions Scenario: RCP 8.5
Time Period: 2050
Model Description: Maximum Consensus
Analogue Towns:
Cootamundra, Wangaratta, Corowa,
Wagga Wagga, Benalla,
Albury-Wodonga, Mudgee,

Location: Canberra
Emissions Scenario: RCP 8.5
Time Period: 2090
Model Description: Maximum Consensus
Analogue Towns:
Muswellbrook, Scone, Gilgandra, Warwick,
Condobolin, Dubbo, Wellington, Parkes,
Forbes, West Wyalong

Figure 9: CSIRO Climate Analogue tool screenshots showing results and analogue towns using the following parameters: Location of Interest - Canberra; Emission Scenario: RCP 8.5; Description – Maximum Consensus; Time period – 2030, 2050 & 2090

5.4.3. Extreme Temperatures

A wide range of extreme weather events is expected in most regions of the world even with an unchanging climate, so it is difficult to attribute any individual event to a change in the climate. However, simple statistical reasoning indicates that substantial changes in the frequency of extreme events can result from a relatively small shift of the distribution of a weather or climate variable (IPCC, 2007). More simply, increases in the average temperature can result in increases in hot weather, record hot weather and record extreme temperatures and subsequently less cold temperatures and weather and less cold temperature extremes (Figure 10). Given that Canberra's temperatures are projected to increase 4.2°C by 2090 (Table 5), it is prudent to predict that Canberra hot weather and extreme hot temperatures will rise accordingly, although neither NARCliM and CSIRO analogue have made projections other than an increase in heatwave events (NARCliM 2016).

Despite this, climate and weather are a complex interaction between many variables whose relationship can be is difficult to predict, isolate or model. This is particularly evident in Canberra weather in the last few years. In 2017, Canberra experienced 18 days over 35° including 2 days over 40°C (BOM, 2018a). In 2016, Canberra experienced 11 day over 35°C and no days above 40 (BOM, 2018b), while in 2015 Canberra only experienced 5 days above 35° and no days above 40 (BOM, 2018c). According to the projections (

Table 2), experiencing 18 hot days is very close to 2070 projection, while 5 days is below the number of hot days Canberra's current climate experiences.

In addition, Canberra's current record high is 42.2°C set on 1st February 1968 (BOM, 2018d), and more recent highs include 41.6 on both 18th Jan 2013 (BOM, 2018e) and 11th Feb 2017 (BOM, 2018a). Despite 2017 being the hottest summer in Canberra for 75 years, Canberra did not experience a new record high, although it was only 0.6°C short.

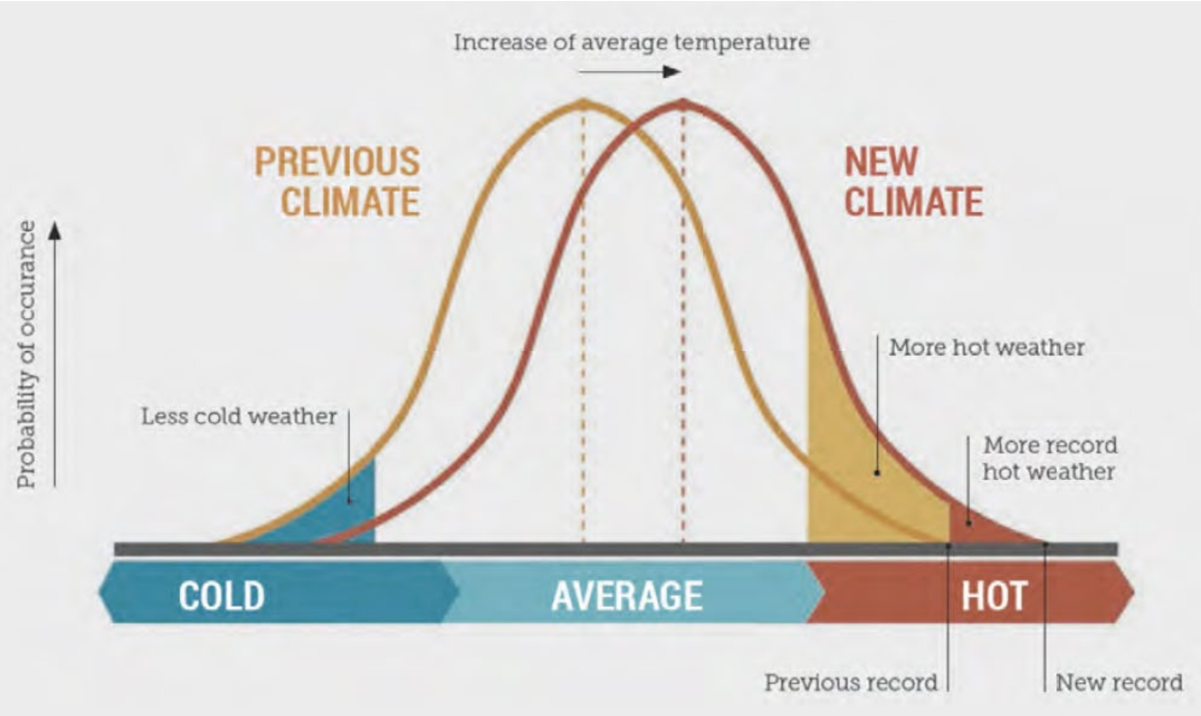


Figure 10: Schematic showing the effect on extreme temperatures when the mean temperature increases, for a normal temperature distribution (ESPDD, 2016, modified from IPCC 2007, p. 19, Figure 2)

5.4.4. Storms

Annual rainfall in the ACT is projected to remain stable; however, storms will become more frequent and more intense (ESPDD 2016). Intense rainfall generally does not have time to soak into the ground and becomes stormwater run-off. This is critically important, as even though ACT projected to receive the same annual rainfall into the future, much of it may be runoff and therefore will be unavailable for urban trees. This will further increase any water unavailability issues (drought, rainfall variability, soil volume restrictions) for the Canberra's urban forest and living infrastructure. A recent example of this was on 23rd/24th February 2018 when Canberra received more than a month's average rainfall in a day (Back, 2018), after which Canberra has experienced little significant rainfall and is currently (October, 2018) in drought.

5.5. Scenario assumptions

The multi-criteria matrix was analysed to take into account the assumptions for each scenario (Table 6). Depending on the scenario, certain criteria were considered more important than others in determining the suitability of tree species. Raising the importance of a criterion involved either excluding full criteria or excluding certain data within in a criterion. E.g. In lanes and narrow verges scenario, species with canopies over 6m were excluded, as they would not fit in this setting.

Table 6: Description of scenarios, assumptions for each scenario and actions taken in the analysis to take the assumptions into account.

Scenario	Assumptions *(based on discussions with TCCS)*	Action
High pedestrian traffic pavements with strata cells	• Extreme heat important • Heat tolerance important • Drought tolerance very important - high pedestrian areas can exacerbate drought conditions. • Clearance important • High use area – allergen important • Expensive establishment – longevity important • Usually not irrigated • Shade very important • No inner asset protection zone issues • *Low litter and fruiting/acorns may present issues • *Possibly restrictions on max ASV • *Aesthetics very important	• Extreme heat - Scores 1 to 3 excluded • Drought Tolerance - Scores 1 to 3 excluded • Trees ≤ 5m tall excluded • Allergen – Scores 1 & 2 excluded • Longevity – Score 1 & 2 excluded • Irrigation – Score 1 excluded • Tree with shade scores 1 & 2 excluded • Species plants excluded
Low pedestrian traffic dryland grass or gravel	• Extreme heat important • Heat tolerance important • Drought tolerance important • Asset protection zone important • Water is a limiting a factor • Shade very important • *Most common scenario in Canberra	• Extreme heat - Scores 1 & 2 excluded • Drought Tolerance - Scores 1 & 2 excluded • Asset Protection Zone – No excluded • Allergen – Scores 1 & 2 excluded • Weed Potential – Score 1 excluded • Irrigation – Score 1 to 3 excluded • Tree with shade scores 1 to 2 excluded • Species plants excluded
Irrigated grass conditions	• Extreme heat less of an issue due to water availability • Less drought tolerance needed • Possible asset protection zone issues • No limit on water • Shade less important • Special plants included as irrigated area are usually high aesthetic areas.	• Extreme heat - Scores 1 excluded • Drought Tolerance - Scores 4 & 5 excluded • Asset Protection Zone – No excluded • Allergen – Scores 1 & 2 excluded • Irrigation – Score 5 excluded

Lanes and narrow verges	• Narrow width – max 6m canopy • Restrictions on ASV, no ASV over 25-30m^3 • Asset Protection Zone – no excluded • Shade moderately importance • Clearance & visibility important • Similar to low pedestrian areas	• Extreme heat - Scores 1 & 2 excluded • Drought Tolerance - Scores 1 & 2 excluded • Asset Protection Zone – No excluded • Canopies >6m wide excluded • Available soil volume over 30m^3 excluded • Allergen – Scores 1 & 2 excluded • Weed Potential – Score 1 excluded • Irrigation – Score 1 to 3 excluded • Tree with shade scores 1 to 2 excluded • Species plants excluded
Local and collector streets	• Average width – max 15m canopy width • No very large ASV, No ASV over 100m^3 • Shade very important • Some restrictions on ASV • Visibility important • Very similar to Low pedestrian areas • One of the most common scenarios	• Extreme heat - Scores 1 & 2 excluded • Drought Tolerance - Scores 1 & 2 excluded • Asset Protection Zone – No excluded • Canopies >15m wide excluded • Available soil volume over 100m^3 excluded • Allergen – Scores 1 & 2 excluded • Weed Potential – Score 1 excluded • Irrigation – Score 1 to 3 excluded • Tree with shade scores 1 to 2 excluded • Species plants excluded
Avenues and arterial roads	• Wide width • Aesthetics important • No restrictions on ASV • Some restrictions on visibility or clearance • Shade moderately important • Asset protection zone issues • Similar to Low pedestrian areas	• Extreme heat - Scores 1 & 2 excluded • Drought Tolerance - Scores 1 & 2 excluded • Asset Protection Zone – No excluded • Tree heights <10 excluded • Allergen – Scores 1 & 2 excluded • Weed Potential – Score 1 excluded • Irrigation – Score 1 to 3 excluded • Tree with shade scores 1 to 2 excluded • Species plants excluded

6. Results

6.1. Top and Bottom 50 ranked species

For effective analysis of the trends and patterns of the multi-criteria analysis, an arbitrary top and bottom 50-ranked species was established. This identified the most and least suitable species across all criteria.

An analysis of the non-weighted ranking and climate-based ranking methods found that there was little difference between the top 50-ranked species. Between the methods, there were only 4 species difference and the top 15 species were the same across ranking methods although their order was different (Table 7). In the bottom 50-ranked species, there were 6 species difference between the methods (Table 8).
As there was little difference between the non-weighted and climate weighted methods, the following results (top and bottom 50 and scenario recommendations) are based on the non-weighted data.

Species that are in the top 50 (Table 9) scored between 33 and 37 out of 40, while species in the bottom 50 scored between 21 and 28 out of 40. It must be noted the top 50 and bottom 50 ranked species are arbitrary and it has limitations; e.g. the species ranked 50th (*Acacia Pendula*) has the same score (33) as the following 18 species which are ranked 51-68th. When species have the same score they are ordered alphabetically. As a result, *Acacia pendula* is the highest ranked species with the score 33 and *Quercus rubra* is the lowest ranked species with the score 33. The same can be said for bottom 50 where tree species (*Callistemon viminalis* 'Dawson River Weeper') ranked 162 (best of the bottom 50) and has the same score as 7 other tree species ranked 155-161st. This phenomenon it observed throughout the criteria matrix.

Table 7: Comparison of top 50 non-weighted ranked and climate weighted ranked, # highlighted cells indicate species that are not common across ranking methodologies.

Non Weighted Rank	Species Name	Climate Weighted Rank	Species Name
1	Brachychiton populneus	1	Brachychiton populneus
2	Casuarina cunninghamiana subsp. cunninghamiana	2	Casuarina cunninghamiana subsp. cunninghamiana
3	Cupressus arizonica	3	Cupressus arizonica
4	Cupressus torulosa	4	Cupressus torulosa
5	Eucalyptus baueriana (Eucalyptus bauerana)	5	Eucalyptus baueriana (Eucalyptus bauerana)
6	Eucalyptus melliodora	6	Eucalyptus melliodora
7	Eucalyptus melliodora (Tarcutta form)	7	Eucalyptus melliodora (Tarcutta form)
8	Eucalyptus microcarpa (E. woollsiana)	8	Eucalyptus microcarpa (E. woollsiana)
9	Eucalyptus radiata	9	Eucalyptus radiata
10	Eucalyptus albens	10	Eucalyptus gracilis
11	Eucalyptus dealbata	11	Pinus pinea
12	Eucalyptus gracilis	12	Eucalyptus albens
13	Eucalyptus viminalis	13	Eucalyptus dealbata
14	Pinus pinea	14	Eucalyptus viminalis
15	Callitris endlicheri	15	Callitris endlicheri
16	Eucalyptus goniocalyx	16	Eucalyptus sideroxylon
17	Eucalyptus polyanthemos subsp. polyanthemos	17	Eucalyptus sideroxylon 'Rosea'
18	Eucalyptus sideroxylon	18	Pinus eldarica
19	Eucalyptus sideroxylon 'Rosea'	19	Pistacia chinensis (P. sinensis) MALE CLONE ONLY
20	Liquidambar styraciflua 'Palo Alto'	20	Eucalyptus goniocalyx
21	Pinus eldarica	21	Liquidambar styraciflua 'Palo Alto'
22	Pistacia chinensis (P. sinensis) MALE CLONE ONLY	22	Quercus ilex
23	Quercus frainetto #	23	Quercus lobata
24	Quercus ilex	24	Quercus macrocarpa
25	Quercus lobata	25	Eucalyptus polyanthemos subsp. polyanthemos
26	Quercus macrocarpa	26	Callitris glaucophylla
27	Callitris glaucophylla	27	Cedrus atlantica 'Glauca'
28	Cedrus atlantica 'Glauca'	28	Lagerstroemia fauriei 'Kiowa'
29	Cupressus sempervirens 'Stricta'	29	Lagerstroemia x L. fauriei 'Osage'
30	Cupressus sempervirens 'Swane's Golden'	30	Lagerstroemia x L. fauriei 'Biloxi'
31	Eucalyptus andrewsii #	31	Lagerstroemia x L. fauriei 'Muskogee'
32	Eucalyptus benthamii	32	Lagerstroemia x L. fauriei 'Natchez'
33	Eucalyptus mannifera	33	Lagerstroemia x L. fauriei 'Sioux'
34	Eucalyptus rossii #	34	Lagerstroemia x L. fauriei 'Tuscarora'
35	Lagerstroemia fauriei 'Kiowa'	35	Liquidambar styraciflua 'Tiriki'
36	Lagerstroemia x L. fauriei 'Osage'	36	Melia azedarach 'Elite'
37	Lagerstroemia x L. fauriei 'Biloxi'	37	Pinus sabiniana
38	Lagerstroemia x L. fauriei 'Muskogee'	38	Pinus torreyana
39	Lagerstroemia x L. fauriei 'Natchez'	39	Casuarina glauca #
40	Lagerstroemia x L. fauriei 'Sioux'	40	Quercus frainetto #
41	Lagerstroemia x L. fauriei 'Tuscarora'	41	Cupressus sempervirens 'Stricta'
42	Liquidambar styraciflua 'Tiriki'	42	Cupressus sempervirens 'Swane's Golden'
43	Melia azedarach 'Elite'	43	Eucalyptus benthamii
44	Pinus sabiniana	44	Eucalyptus mannifera
45	Pinus torreyana	45	Quercus douglasii
46	Quercus douglasii	46	Quercus suber
47	Quercus palustris 'Free Fall' #	47	Ulmus parvifolia 'Emer II' Alee
48	Quercus suber	48	Acacia pendula
49	Ulmus parvifolia 'Emer II' Alee	49	Gleditsia triacanthos 'Sunburst' #

Non Weighted Rank	Species Name	Climate Weighted Rank	Species Name
50	Acacia pendula	50	Allocasuarina littoralis #

species is not common across ranking methodologies

Table 8 Comparison of bottom 50 non-weighted ranked and climate weighted ranked species, # highlighted cells indicate species that are not common across ranking methodologies.

Non Weighted Rank	Species Name	Climate Weighted Rank	Species Name
162	Callistemon viminalis 'Dawson River Weeper' #	162	Acer palmatum 'Trompenburg' #
163	Crataegus laevigata (syn. oxycantha) 'Paul's Scarlet' #	163	Acer rubrum 'October Glory' #
164	Eucalyptus maidenii (E. globulus subsp. maidenii)	164	Acer x freemanii 'Jeffersred' Autumn Blaze #
165	Fraxinus ornus #	165	Eucalyptus maidenii (E. globulus subsp. maidenii)
166	Juglans nigra #	166	Malus floribunda
167	Malus floribunda	167	Malus halliana 'Parkmanii'
168	Malus halliana 'Parkmanii'	168	Malus x purpurea
169	Malus x purpurea	169	Populus yunnanensis 'Gundaroo'
170	Parrotia persica #	170	Zelkova serrata
171	Populus yunnanensis 'Gundaroo'	171	Acacia caerulescens
172	Tilia cordata	172	Arbutus andrachne
173	Ulmus parvifolia 'Yarralumla Clone' #	173	Prunus cerasifera 'Pissardii'
174	Ulmus procera	174	Prunus persica
175	Zelkova serrata	175	Liriodendron tulipifera #
176	Acacia caerulescens	176	Acer griseum #
177	Acer buergerianum	177	Acer platanoides 'Crimson King' #
178	Acer grosseri var. Hersii	178	Tilia cordata
179	Acer japonicum	179	Ulmus procera
180	Acer japonicum 'Vitifolium'	180	Acacia covenyi
181	Arbutus andrachne	181	Prunus cerasifera 'Oakville Crimson Spire'
182	Eucalyptus moorei	182	Acer buergerianum
183	Malus tschonoskii	183	Acer grosseri var. Hersii
184	Prunus cerasifera 'Pissardii'	184	Acer japonicum
185	Prunus persica	185	Acer japonicum 'Vitifolium'
186	Acacia covenyi	186	Eucalyptus moorei
187	Angophora costata	187	Malus tschonoskii
188	Eucalyptus apiculata	188	Angophora costata
189	Eucalyptus parvula	189	Fraxinus excelsior 'Aurea Pendula'
190	Fraxinus excelsior 'Aurea Pendula'	190	Fraxinus excelsior 'Aurea'
191	Fraxinus excelsior 'Aurea'	191	Eucalyptus apiculata
192	Larix decidua	192	Eucalyptus parvula
193	Prunus cerasifera 'Oakville Crimson Spire'	193	Prunus padus
194	Prunus padus	194	Acacia melanoxylon
195	Acacia melanoxylon	195	Eucalyptus lacrimans (E. pauciflora Tantangera form)
196	Acer platanoides	196	Larix decidua
197	Acer platanoides 'Crimson Sentry'	197	Acer platanoides 'Crimson Sentry'
198	Eucalyptus lacrimans (E. pauciflora Tantangera form)	198	Prunus 'Shirotae' ('Mt. Fuji')
199	Prunus 'Shirotae' ('Mt. Fuji')	199	Prunus 'Sekiyama' ('Kanzan')
200	Prunus 'Sekiyama' ('Kanzan')	200	Prunus 'Shirofugen'
201	Prunus 'Shirofugen'	201	Prunus campanulata
202	Prunus campanulata	202	Prunus mume
203	Prunus mume	203	Prunus serrulata
204	Prunus serrulata	204	Prunus x yedoensis

Non Weighted Rank	Species Name	Climate Weighted Rank	Species Name
205	Prunus x yedoensis	205	Paulownia tomentosa
206	Paulownia tomentosa	206	Acer platanoides
207	Prunus ‘Amanogawa’	207	Prunus ‘Amanogawa’
208	Quillaja saponaria	208	Quillaja saponaria
209	Toona sinensis	209	Toona sinensis
210	Betula pendula	210	Betula pendula
211	Betula pendula ‘Laciniata’	211	Betula pendula ‘Laciniata’

species is not common across ranking methodologies

Table 9: Top 50 trees and their Multi-Criteria matrix scores and rank.

Multi - Criteria Rank	Category	Restrictions	Species Name	Extreme Heat Tolerance	Drought Tolerance	Frost Tolerance	Temperature Vulnerability Extreme	Leaf Persistence	Commercially available?	Inner Asset protection zone	Height	Height Descriptive	Width	Width Descriptive	Tree shape category	Available Soil Volume m3 Not less than	Potential as Allergen	Longevity	Weed Potential Score	Irrigation Score	Shade Type/ Density	Non Weighted Score (40)
1	Native Trees 10-15m	New Species	Brachychiton populneus	5	5	4	Green	Evergreen	Yes	Yes	11	Medium	9	Medium	1	27	5	5	5	5	3	**37**
2	Native Trees >15m		Casuarina cunninghamiana subsp. cunninghamiana	5	5	4	Green	Evergreen	Yes	Yes	19	Tall	13.5	Wide	1	60	5	5	5	5	3	**37**
3	Conifer Trees		Cupressus arizonica	5	5	4	Green	Evergreen	Yes	Yes	20	Tall	13.5	Wide	4	60	4	5	5	5	4	**37**
4	Conifer Trees		Cupressus torulosa	5	5	4	Yellow	Evergreen	Yes	No	17.5	Tall	9	Medium	4	27	3	5	5	5	5	**37**
5	Native Trees >15m		Eucalyptus baueriana (Eucalyptus bauerana)	5	5	4	Orange	Evergreen	Yes	No	17.5	Tall	15	Wide	1	60	5	4	5	5	4	**37**
6	Native Trees >15m		Eucalyptus melliodora	5	5	4	Yellow	Evergreen	Yes	Yes	22.5	Tall	20	Wide	1	106	5	5	5	5	3	**37**
7	Native Trees >15m		Eucalyptus melliodora (Tarcutta form)	5	5	4	Yellow	Evergreen	Yes	Yes	22.5	Tall	20	Wide	1	106	5	5	5	5	3	**37**
8	Native Trees >15m		Eucalyptus microcarpa (E. woollsiana)	5	4	4	Yellow	Evergreen	Yes	Yes	20	Tall	13.5	Wide	1	60	5	5	5	5	4	**37**
9	Native Trees >15m	New Species	Eucalyptus radiata	4	5	4	Orange	Evergreen	Yes	Yes	22.5	Very Tall	17.5	Wide	1	106	5	5	5	5	4	**37**
10	Native Trees >15m		Eucalyptus albens	4	5	4	Yellow	Evergreen	Yes	Yes	17.5	Tall	12.5	Wide	1	60	5	4	5	5	4	**36**
11	Native Trees 10-15m		Eucalyptus dealbata	4	5	4	No Data	Evergreen	Yes	Yes	12	Medium	8	Medium	1	17	5	5	5	5	3	**36**
12	Native Trees 10-15m	New Species	Eucalyptus gracilis	5	5	4	No Data	Evergreen	Yes	No	9	Medium	6	Medium	2	17	5	5	5	5	2	**36**
13	Native Trees >15m	Special Plant	Eucalyptus viminalis	4	5	4	Orange	Evergreen	Yes	No	22.5	Tall	17.5	Wide	1	106	5	5	5	5	3	**36**
14	Conifer Trees		Pinus pinea	5	5	4	Green	Evergreen	Yes	Yes	15	Medium	12	Wide	1	38	3	5	5	5	4	**36**
15	Native Trees 10-15m	Special Plant	Callitris endlicheri	5	5	4	No Data	Evergreen	Yes	Yes	13.5	Medium	3.5	Narrow	3	60	5	3	5	5	3	**35**
16	Native Trees >15m		Eucalyptus goniocalyx	4	5	4	orange	Evergreen	Yes	No	20	Tall	15	Wide	1	60	5	4	5	5	3	**35**
17	Native Trees >15m		Eucalyptus polyanthemos subsp. polyanthemos	3	5	4	Yellow	Evergreen	Yes	Yes	20	Tall	15	Wide	1	60	5	5	5	5	3	**35**
18	Native Trees >15m		Eucalyptus sideroxylon	5	5	4	Green	Evergreen	Yes	Yes	18	Tall	12	Wide	1	38	5	4	5	5	2	**35**
19	Native Trees >15m		Eucalyptus sideroxylon 'Rosea'	5	5	4	Green	Evergreen	Yes	Yes	18	Medium	12	Wide	1	38	5	4	5	5	2	**35**
20	Introduced Trees 10-15m		Liquidambar styraciflua 'Palo Alto'	4	5	4	Green	Deciduous	Yes	Yes	13.5	Medium	12	Wide	4	38	5	5	5	3	4	**35**
21	Conifer Trees	New Species	Pinus eldarica	5	5	4	No Data	Evergreen	No	No	15	Tall	10	Medium	4	27	3	5	5	5	3	**35**
22	Introduced Trees <10m		Pistacia chinensis (P. sinensis) MALE CLONE ONLY	5	5	4	Green	Deciduous	Yes	Yes	9	Short	6	Medium	2	10	5	3	5	5	3	**35**
23	Introduced Trees >15m	New Species	Quercus frainetto	2	5	4	No Data	Deciduous	No	Yes	20	Tall	20	Wide	1	106	4	5	5	5	5	**35**
24	Introduced Trees 10-15m		Quercus ilex	4	5	4	Green	Evergreen	Yes	Yes	13.5	Medium	13.5	Wide	1	60	4	5	3	5	5	**35**
25	Introduced Trees >15m	New Species	Quercus lobata	4	5	4	Yellow	Deciduous	No	Yes	18	Tall	15	Wide	1	60	4	5	5	5	3	**35**
26	Introduced Trees >15m	New Species	Quercus macrocarpa	4	5	4	Orange	Deciduous	Yes	Yes	22.5	Tall	13.5	Wide	1	106	4	5	5	5	3	**35**
27	Native Trees 10-15m	New Species	Callitris glaucophylla	5	4	4	No Data	Evergreen	Yes	No	15	Medium	9	Medium	4	27	5	5	5	3	3	**34**
28	Conifer Trees		Cedrus atlantica 'Glauca'	5	4	4	Orange	Evergreen	Yes	Yes	20	Tall	17.5	Wide	4	106	3	5	5	5	3	**34**
29	Conifer Trees		Cupressus sempervirens 'Stricta'	3	5	4	Green	Evergreen	Yes	No	12.5	Medium	4	Narrow	3	60	4	5	5	5	3	**34**
30	Conifer Trees		Cupressus sempervirens 'Swane's Golden'	3	5	4	Green	Evergreen	Yes	No	12.5	Medium	4	Narrow	3	60	4	5	5	5	3	**34**
31	Native Trees >15m		Eucalyptus andrewsii	2	5	4	No Data	Evergreen	Yes	No	20	Very Tall	15	Wide	1	60	5	5	5	5	3	**34**
32	Native Trees >15m	New Species	Eucalyptus benthamii	5	3	4	No Data	Evergreen	Yes	No	20	Tall	15	Wide	1	106	5	5	5	3	4	**34**
33	Native Trees >15m		Eucalyptus mannifera	3	5	4	Orange	Evergreen	Yes	Yes	20	Tall	13.5	Wide	1	60	5	4	5	5	3	**34**
34	Native Trees >15m		Eucalyptus rossii	3	4	4	Green	Evergreen	Yes	Yes	16.5	Medium	15	Wide	1	60	5	5	5	5	3	**34**
35	Introduced Trees <10m	New Species	Lagerstroemia fauriei 'Kiowa'	4	5	4	Green	Deciduous	Yes	Yes	8	Short	8	Medium	3	17	5	3	5	5	3	**34**
36	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Osage'	4	5	4	Green	Deciduous	Yes	Yes	8	Short	8	Medium	5	17	5	3	5	5	3	**34**
37	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Biloxi'	4	5	4	Green	Deciduous	Yes	Yes	7	Short	5	Narrow	5	7	5	3	5	5	3	**34**
38	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Muskogee'	4	5	4	Green	Deciduous	Yes	Yes	6	Short	5	Narrow	5	7	5	3	5	5	3	**34**
39	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Natchez'	4	5	4	Green	Deciduous	Yes	Yes	8	Short	6	Medium	5	10	5	3	5	5	3	**34**
40	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Sioux'	4	5	4	Green	Deciduous	Yes	Yes	5	Short	3	Narrow	5	2	5	3	5	5	3	**34**
41	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Tuscarora'	4	5	4	Green	Deciduous	Yes	Yes	6	Short	4	Narrow	5	4	5	3	5	5	3	**34**
42	Introduced Trees 10-15m		Liquidambar styraciflua 'Tiriki'	4	5	4	Green	Deciduous	Yes	Yes	12	Medium	10	Medium	4	27	5	5	5	3	3	**34**
43	Native Trees <10m	New Species	Melia azedarach 'Elite'	5	4	4	Green	Deciduous	Yes	Yes	8	Short	9	Medium	2	21	4	3	5	5	4	**34**
44	Conifer Trees		Pinus sabiniana	4	5	4	No Data	Evergreen	Yes	Yes	15	Tall	10	Medium	4	27	3	5	5	5	3	**34**
45	Conifer Trees		Pinus torreyana	4	5	4	No Data	Evergreen	No	Yes	17.5	Tall	15	Wide	4	60	3	5	5	5	3	**34**
46	Introduced Trees 10-15m	New Species	Quercus douglasii	3	5	4	Yellow	Deciduous	No	Yes	15	Medium	12	Wide	1	38	4	5	3	5	5	**34**
47	Introduced Trees >15m		Quercus palustris 'Free Fall'	3	4	4	Orange	Deciduous	Yes	Yes	18	Tall	15	Wide	1	60	4	5	5	5	4	**34**
48	Introduced Trees 10-15m		Quercus suber	4	4	4	Green	Evergreen	No	Yes	15	Medium	15	Wide	1	60	4	5	3	5	5	**34**
49	Introduced Trees 10-15m	New Species	Ulmus parvifolia 'Emer II' Alee	4	4	4	Green	Deciduous	Yes	Yes	13	Medium	10	Medium	1	27	4	5	3	5	5	**34**
50	Native Trees <10m	New Species	Acacia pendula	5	4	4	Green	Evergreen	Yes	Yes	8	Short	5	Narrow	2	7	3	4	5	5	3	**33**

Genus: 14 Genera – Dominated by *Eucalyptus* (17), *Lagerstroemia* (7), *Quercus* (7); **Species:** 50 Species; **Leaf Persistence:** 17 Deciduous, 33 Evergreen; **MIS 25 History:** 20 new species, 2 special plants; **Origin:** 27 introduced, 23 native; **Height:** 40 species over 10m, 10 species <10m; **Temperature Vulnerability:** 24 Green, 8 Yellow, 8 Orange, 10 No data

In the top 50 ranked trees, approximately half (56% / 28) were introduced and half (44% / 22) were native species. In the bottom 50 ranked species 41 species (82%) were introduced, while 9 (18%) were native (Figure 11).

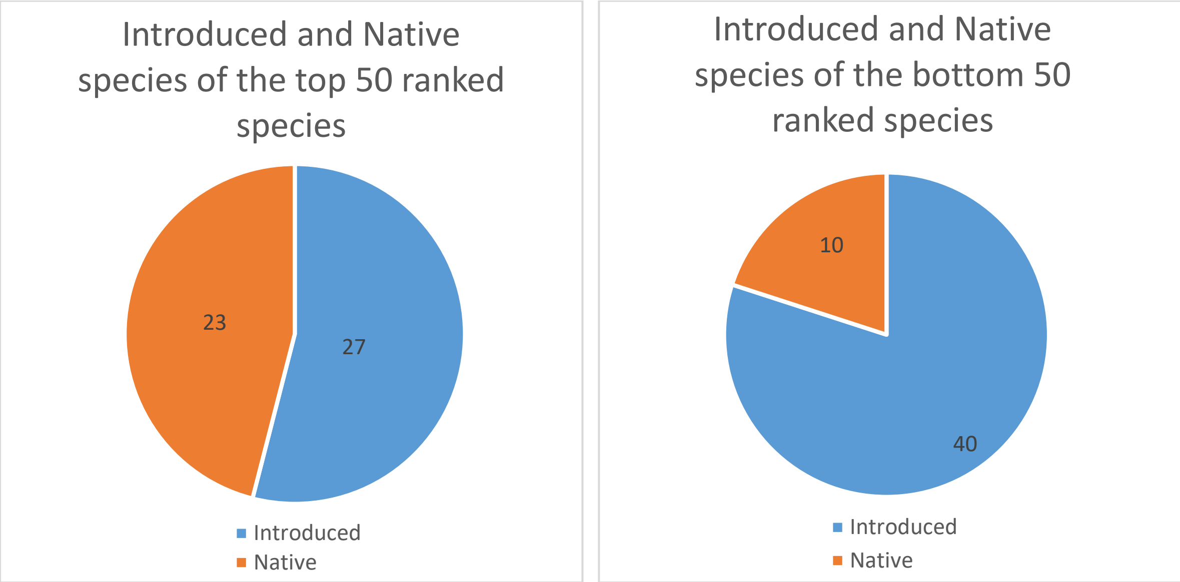


Figure 11: Frequency of introduced and native species in the top and bottom 50 ranked species

Eucalyptus was the highest ranked genus in the top 50 with 34% (17). Conifers (including *Pinus* (4), *Cupressus* (4), and *Cedrus* (1)) ranked second with 9 (18%). Eucalyptus and conifers together made up 52% of the species ranked in the top 50. The remaining tree species include *Lagerstroemia* (7), *Quercus* (7), *Callitrus* (2), *Liquidamber* (2), *Acacia* (1), *Bachychiton* (1), *Casuarina* (1), *Melia* (1), *Pistacia* (1) and *Ulmus* (1) (Figure 12).

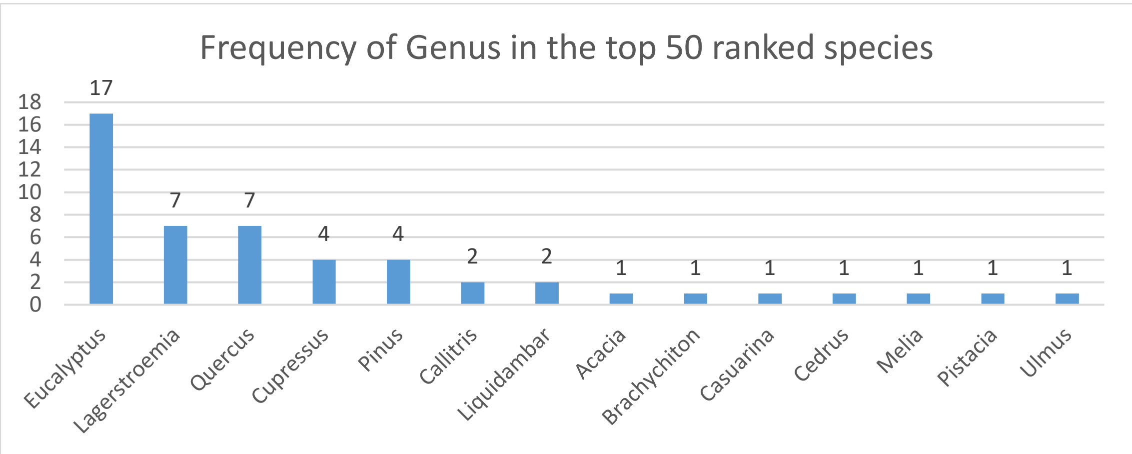


Figure 12: Species frequency in the top 50 ranked species

Prunus and *Acer* were the lowest ranked genera with combined 36% (18) of the bottom 50 species. *Eucalyptus* (5), *Malus* (4), *Acacia* (3) *Fraxinus* (3), *Betula* (2) and *Ulmus* (2) together made up 38% (19) of the species ranked in the bottom 50. The remaining 26% (13) tree species include single species of *Angophora, Arbutus, Callistemon, Crataegus, Juglans, Larix, Parrotia, Paulownia, Populus, Quillaja, Tilia, Toona and Zelkova* (Figure 13).

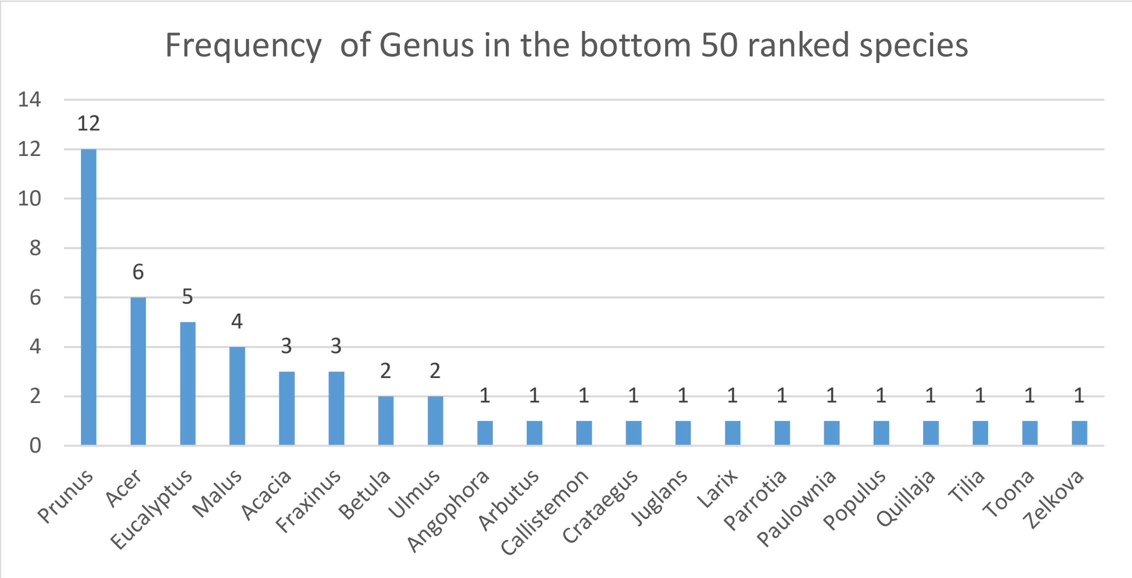


Figure 13: Species frequency in the bottom 50 ranked species

Native trees >15m where the most numerous (16 / 32%) in the top 50 species, while Native trees <10m were the least numerous (2 / 4%). The remaining species were spread over introduced and native across height classes (Figure 14).

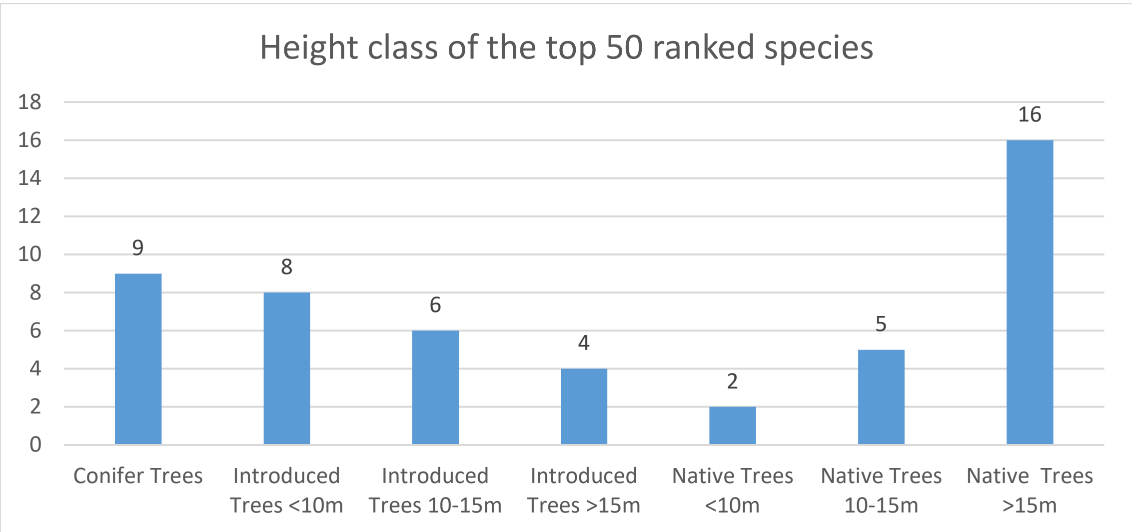


Figure 14: Number of species in each height class in the top 50 ranked species

Introduced trees <10m (23) and 10-15m (14) comprised 74% (37) of the bottom 50. The remaining species were spread even across the other height classes except Native trees species which occurred 6 (12%) in the bottom 50 (

Figure 15).

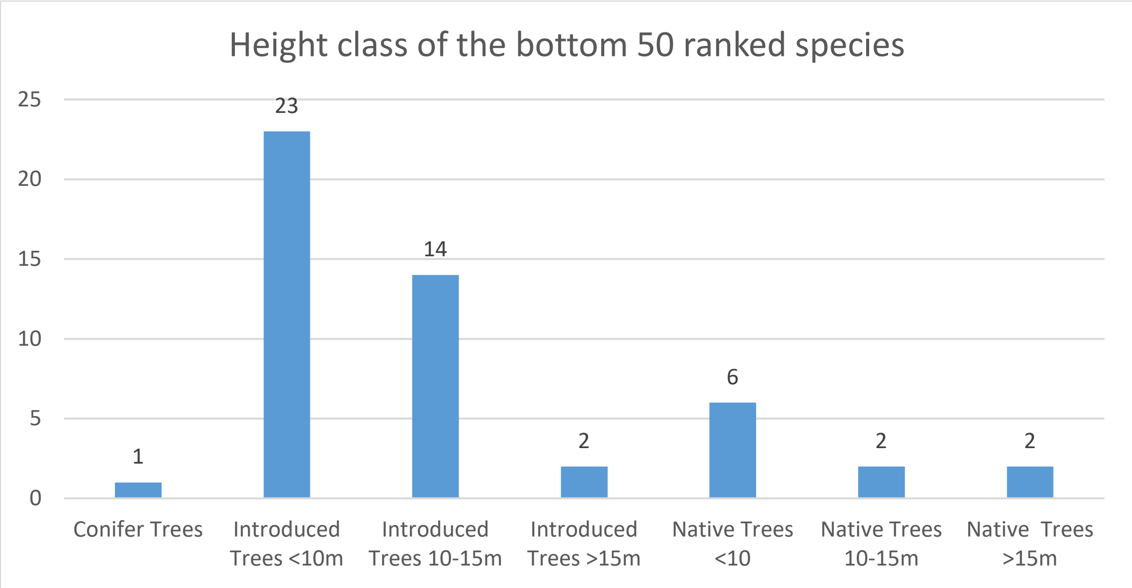


Figure 15: Number of species in each height class in the bottom 50 ranked species

Evergreen species make up 66% (33) of the top 50 species. This compares to 74% (37) deciduous species in the bottom 50 (Figure 16).

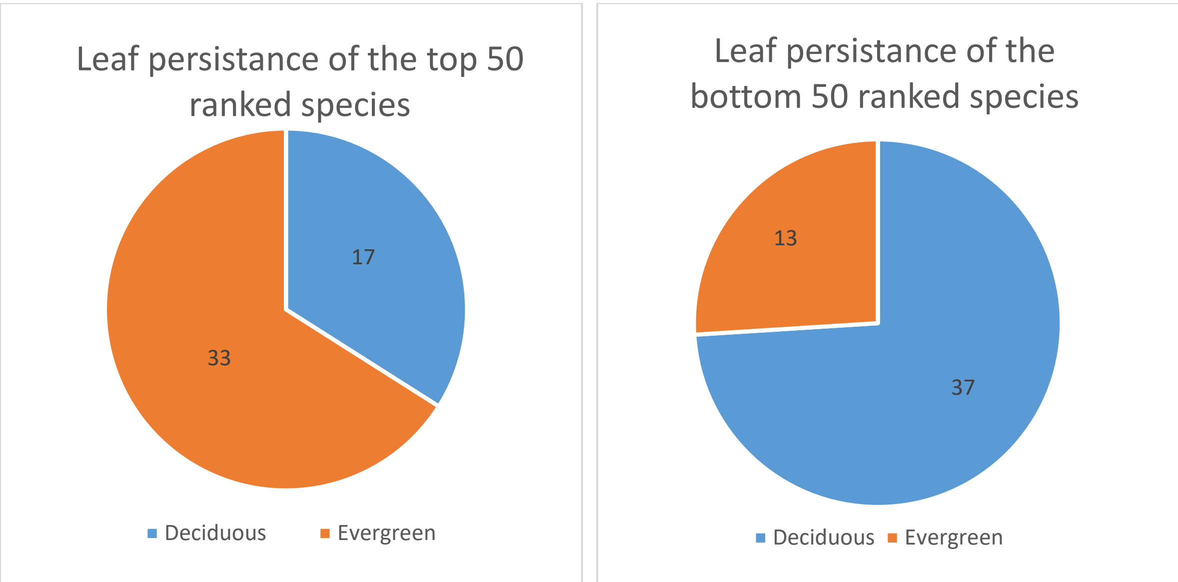


Figure 16: Leaf persistence in the top and bottom 50 ranked species

Seventy eight percent (39) of trees in the top 50 species were compatible with the Asset Protection Zone, while 88% (44) of trees in the bottom 50 ere compatible (Figure 17). Of the 211 MIS species only 39 (18%) were not compatible with the APZ.

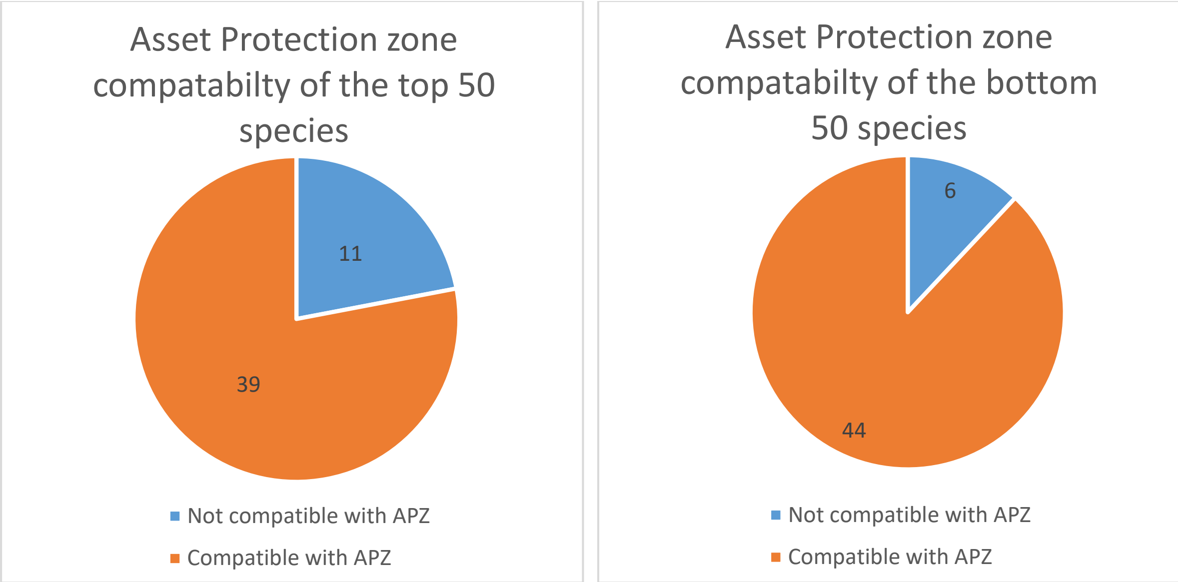


Figure 17: Species compatibility in the asset protection zone in the top and bottom 50 ranked species

Commercially available species make up 88% (44) of the trees in the top 50. The six species that are not commercially available include 4 *Quercus* (*Q. suber, douglasii, lobata and fainetto*) and 2 *Pinus* (*P. eldarica and torreyana*) species. One of these six species (*Quercus suber*) is Forest 1 in the National Arboretum. In the bottom 50 species, 94% (47) are commercially available (Figure 18).

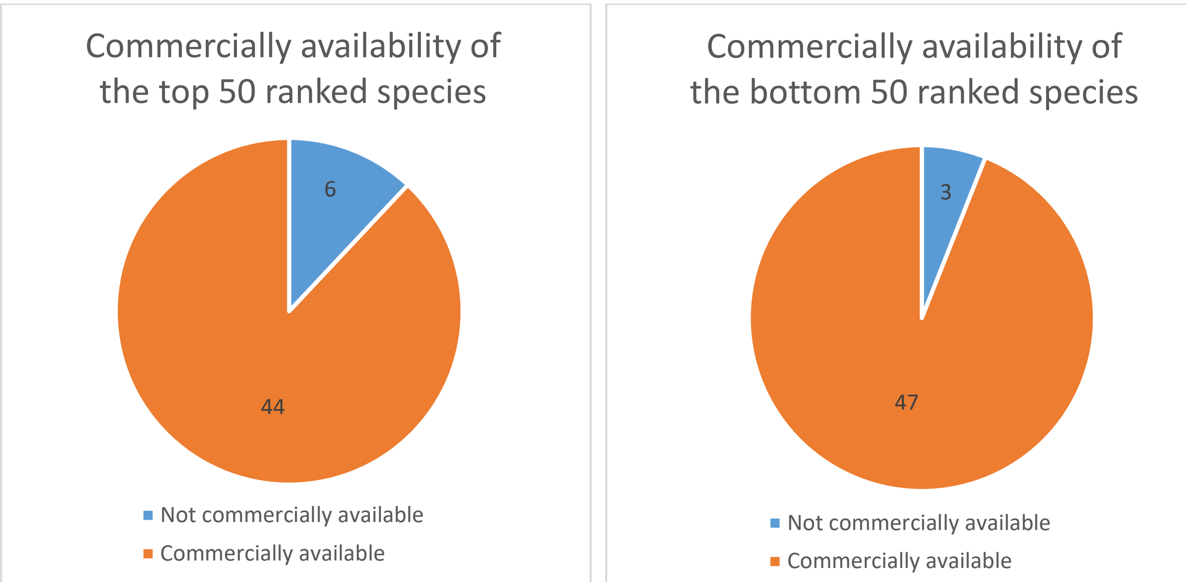
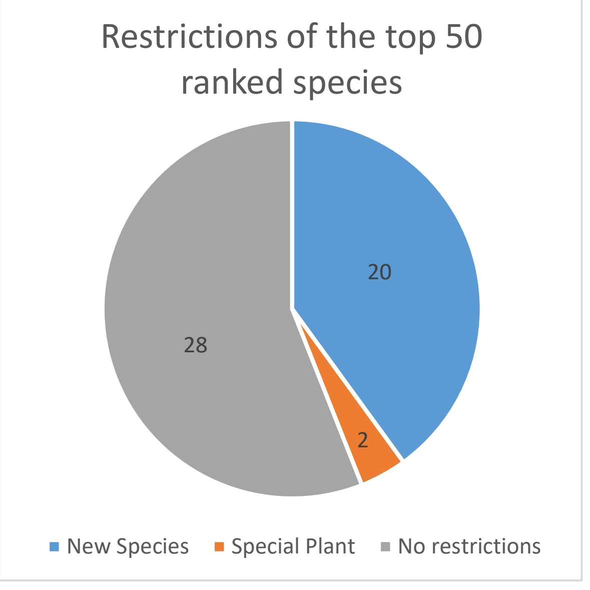


Figure 18: Commercial availability of the top and bottom 50 ranked species

In the top 50, twenty species were categorised as new species, 2 as special plants (*Eucalyptus viminalis, Callitris endlicheri* require written approval is required to use) and 28 have no restrictions. In the bottom 50, 17 species were new, 9 species were special plants

(*Quillaja saponaria*, *Prunus* 'Amanogawa', *Prunus* 'Shirofugen', *Prunus* 'Sekiyama' ('Kanzan'), *Prunus* 'Shirotae' ('Mt. Fuji'), *Eucalyptus lacrimans*, *Angophora costata*, *Ulmus procera*, *Eucalyptus maidenii*) and 24 have no restrictions (Figure 19).



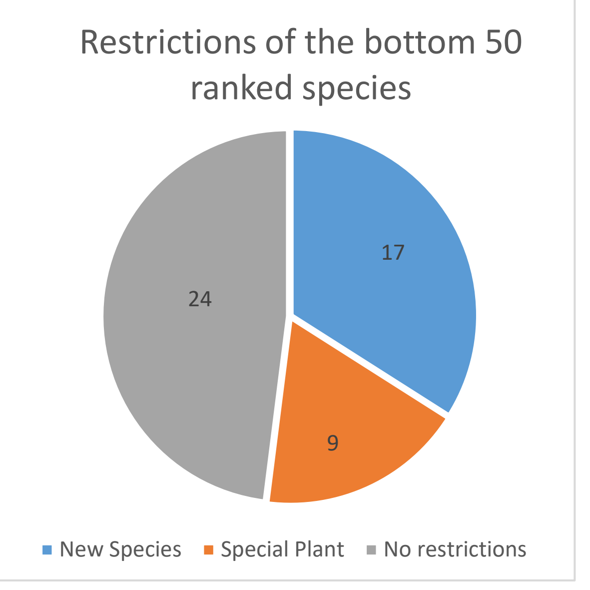


Figure 19: Categories of the top and bottom 50 ranked species.

No species scored Medium to High (Score 2) or High (score 1) as a potential allergen in the top 50 species. In the bottom 50, *Betula pendula 'Laciniata'* and *Betula pendula* both scored Medium to High (Score 2) and Juglans *nigra* scored High (score 1) as a potential allergen (Figure 20). In the complete MIS 25 list, 5 species (*Juglans nigra* and *Platanus orientalis* and three variations/hybrids) scored High (score 1) and 2 species (*Betula pendula 'Laciniata'* and *Betula pendula*) scored Moderate to High (Score 2) for potential allergen. The remaining 206 species scored between Moderate (score 3) to Low (score 5).

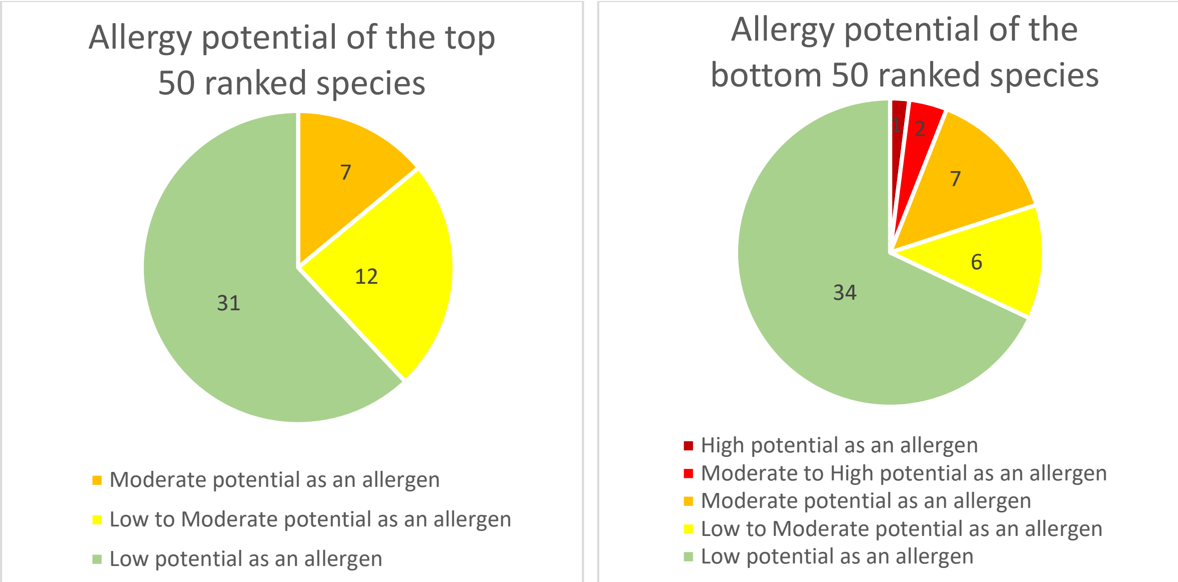


Figure 20: Allergy potential of the top and bottom 50 ranked species.

In the top 50, 4 species (*Quercus ilex*, *Quercus douglasii*, *Quercus suber*, *Ulmus parvifolia* 'Emer II' Alee) are considered medium potential weeds. In the bottom 50, 1 species (*Paulownia tomentose*) had a high weed potential and 20 (40%) species had moderate weed potential (Figure 21). In the full MIS list, only one species has high weed potential, 57 species (27%) have moderate potential and 153 species (72%) have low weed potential.

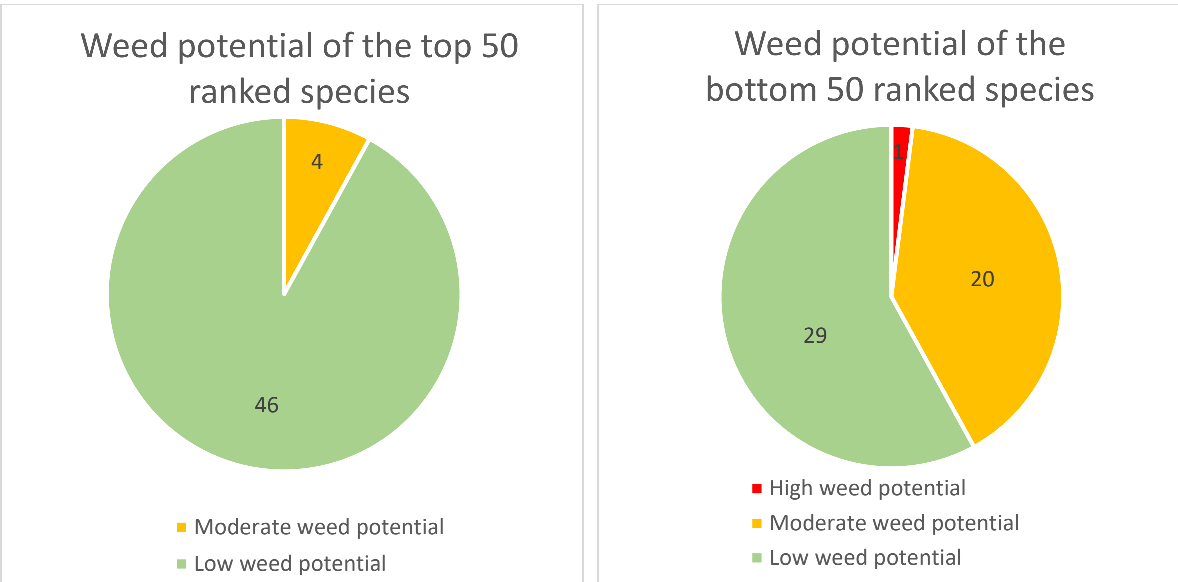


Figure 21: Weed potential of the top and bottom 50 ranked species

Within the top 50 ranked species for temperature vulnerability, almost half (48%) of the species are not considered at risk from increasing temperatures. Sixteen percent of species are slightly at risk and 16% are moderately at risk from increasing temperatures. There was no data for 10 (20%) of species in the top 50. In the bottom 50 there was no data for 22 (44%) species. Ten percent (5) of species are at high risk from increasing temperature while 8 species (16%) are at moderate risk, 9 species (18%) are slightly at risk and 6 species (12%) are not considered at risk (Figure 22). In the entire MIS 25 (211 species), 55 species are not considered at risk from increasing temperatures, 39 are slightly at risk, 37 are at moderate risk, 17 are at high risk from increasing temperature and 63 species has no data.

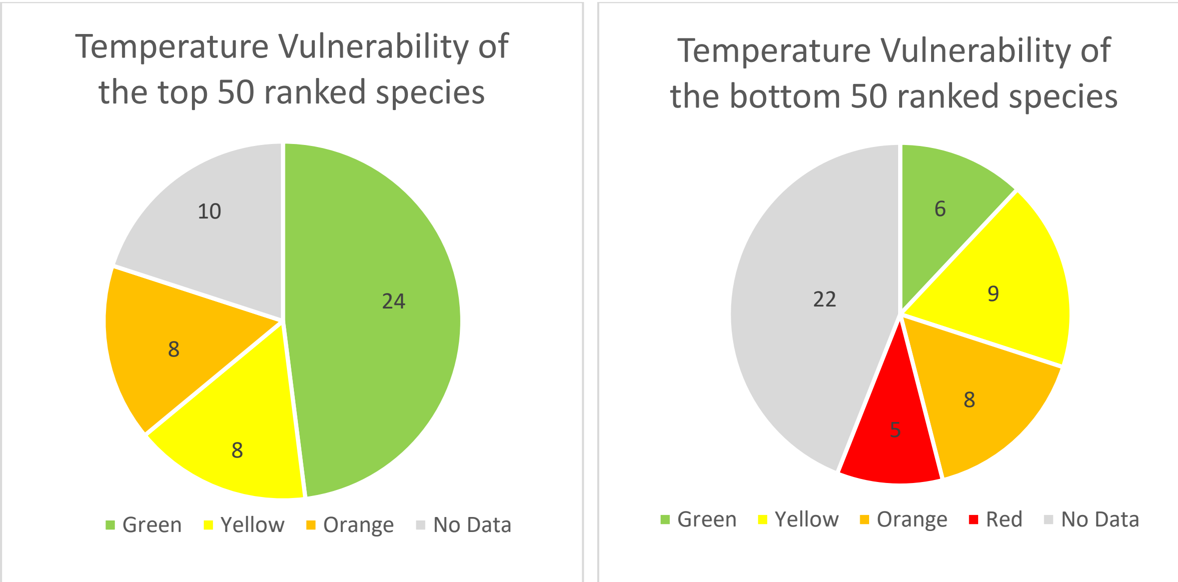


Figure 22: Temperature vulnerability of the top and bottom 50 ranked species. Green indicates species are not considered at risk from increasing temperatures; Yellow indicates species that are slightly at risk from increasing temperatures, Orange indicates species are moderately at risk from increasing temperatures; Red indicates species are at high risk from increasing temperatures, No data indicates species have no temperature vulnerability data for the analysis.

All species in the top 50 were moderately tolerance or better (≥3 score) across all climate criteria (extreme heat, drought and frost tolerance) with the exception of *Quercus frainetto* and *Eucalyptus andrewsii* who scored 2 in extreme heat tolerance. In addition, only 4 species (*Liquidambar styraciflua* ('Palo Alto' and 'Tiriki'), *Callitris glaucophylla*, and *Eucalyptus benthamii*) scored moderate (score 3) for need for irrigation. The remaining species score low (score 5) need for irrigation.

An additional analysis that was conducted included comparing the 50 most abundant species in Canberra (CAUL, 2017) with their multi-criteria ranking. A number of species on the abundance list were not included in the MIS 25. These include *Pinus radiata*, *Populus* *alba*, *Eucalyptus globulus*, *Eucalyptus nicholii*, *Platanus acerifolia*, *Ulmus minor*, *Celtis australis*, *Pyrus ussuriensis*, *Ulmus × hollandica* and *Populus nigra*, [#] highlighted in Table 10.

Table 10: The most abundant trees in Canberra (Kendal, 2017) and a comparison of the abundance rank and multi-criteria matrix rank. # highlighted species indicates species that are in the most abundant trees in Canberra but are not in the MIS 25.

No	Species	Abundance (%)
1	Unknown	
2	*Eucalyptus mannifera*	16.50%
3	*Eucalyptus spp.*	9.95%
4	*Casuarina cunninghamiana*	9.89%
5	*Eucalyptus polyanthemos*	5.12%
6	*Eucalyptus melliodora*	5.00%
7	*Pinus radiate* [#]	3.67%
8	*Fraxinus angustifolia*	3.27%
9	*Pyrus calleryana*	2.34%
10	*Quercus palustris*	2.27%
11	*Eucalyptus blakelyi*	2.15%
12	*Eucalyptus cinerea*	2.12%
13	*Eucalyptus sideroxylon*	2.09%
14	*Populus alba* [#]	1.84%
15	*Ulmus parvifolia*	1.63%
16	*Eucalyptus globulus* [#]	1.52%
17	*Prunus cerasifera*	1.46%
18	*Eucalyptus nicholii* [#]	1.41%
19	*Quercus spp.*	1.35%
20	*Liquidambar styraciflua*	1.17%
21	*Gleditsia triacanthos*	1.17%
22	*Zelkova serrata*	1.02%
23	*Populus spp.*	0.99%
24	*Platanus acerifolia* [#]	0.94%
25	*Ulmus minor* [#]	0.93%
26	*Pistacia chinesis*	0.88%
27	*Quercus lusitanica*	0.84%
28	*Ulmus spp.*	0.73%
29	*Platanus orientalis*	0.68%
30	*Eucalyptus viminalis*	0.65%
31	*Celtis australis* [#]	0.64%
32	*Eucalyptus bridgesiana*	0.59%
33	*Fraxinus spp.*	0.58%
34	*Cedrus atlantica*	0.54%
35	*Styphnolobium japonicum*	0.53%
36	*Pinus spp.*	0.53%
37	*Pyrus ussuriensis*	0.51%
38	*Cupressus spp.*	0.46%
39	*Fraxinus velutina*	0.43%
40	*Quercus robur*	0.43%
41	*Eucalyptus elata*	0.42%
42	*Ulmus x hollandica* [#]	0.40%
43	*Cupressus sempervirens*	0.37%
44	*Quercus cerris*	0.35%
45	*Eucalyptus macrorhyncha*	0.34%
46	*Populus nigra* [#]	0.34%
47	*Platanus spp.*	0.32%
48	*Ulmus americana*	0.29%
49	*Fraxinus americana*	0.28%
50	*Quercus canariensis*	0.28%

Abundance Rank	**Multi - Criteria Rank**	**Species Name**
2	33	Eucalyptus mannifera
4	2	Casuarina cunninghamiana subsp. cunninghamiana
5	17	Eucalyptus polyanthemos subsp. polyanthemos
6	6	Eucalyptus melliodora
8	98	Fraxinus angustifolia subsp. oxycarpa 'Raywood'
9	106	Pyrus calleryana 'Aristocrat'
9	107	Pyrus calleryana 'Chanticleer' syn. 'Cleveland Select'
9	108	Pyrus calleryana 'Red Spire'
9	129	Pyrus calleryana 'Capital'
10	47	Quercus palustris 'Free Fall'
10	65	Quercus palustris
10	87	Quercus palustris 'Pringreen' Green Pillar
11	73	Eucalyptus blakelyi
12	74	Eucalyptus cinerea
13	18	Eucalyptus sideroxylon
15	189	Eucalyptus parvula
17	128	Prunus cerasifera 'Nigra'
17	184	Prunus cerasifera 'Pissardii'
17	193	Prunus cerasifera 'Oakville Crimson Spire'
20	20	Liquidambar styraciflua 'Palo Alto'
20	42	Liquidambar styraciflua 'Tiriki'
20	57	Liquidambar styraciflua
20	58	Liquidambar styraciflua 'Festeri'
21	56	Gleditsia triacanthos 'Sunburst'
21	79	Gleditsia triacanthos 'Shademaster'
21	143	Gleditsia tricanthos var. inermis 'Continental'
22	111	Zelkova serrata 'Green Vase'
22	112	Zelkova serrata 'Musashino'
22	113	Zelkova serrata 'Schmidtlow' (Wireless)
22	175	Zelkova serrata
26	22	Pistacia chinensis (P. sinensis) MALE CLONE ONLY
27	64	Quercus lusitanica
29	83	Platanus (orientalis) x 'Chilensis'
29	103	Platanus orientalis
29	104	Platanus orientalis var. 'Digitata'
29	127	Platanus orientalis var. insularis 'Autumn Glory'
30	13	Eucalyptus viminalis
32	94	Eucalyptus bridgesiana
34	28	Cedrus atlantica 'Glauca'
35	153	Styphnolobium japonicum (Sophora japonica)
39	142	Fraxinus velutina
40	152	Quercus robur
41	116	Eucalyptus elata
43	29	Cupressus sempervirens 'Stricta'
43	30	Cupressus sempervirens 'Swane's Golden'
44	62	Quercus cerris
45	78	Eucalyptus macrorhyncha
48	132	Ulmus americana
49	97	Fraxinus americana
50	85	Quercus canariensis

[#] species that are in the most abundant trees but not in the MIS 25

6.2. Tree Species Recommendations

6.2.1. High pedestrian traffic pavements with strata cells

Table 11: Tree recommendations for high pedestrian traffic pavements with strata cells.

Multi-Criteria Rank	Category	Restrictions	Species Name	Extreme Heat Tolerance	Drought Tolerance	Frost Tolerance	Temperature Vulnerability	Leaf Persistence	Commercially available?	Asset protection zone	Height	Height Descriptive	Width	Width Descriptive	Tree shape category	Available Soil Volume m3 Not less than	Potential as Allergen	Longevity	Weed Potential Score	Irrigation Score	Shade Type/ Density	Non Weighted Score (40)
1	Native Trees 10-15m	New Species	Brachychiton populneus	5	5	4	Green	Evergreen	Yes	Yes	11	Medium	9	Medium	1	27	5	5	5	5	3	**37**
2	Native Trees >15m		Casuarina cunninghamiana subsp. cunninghamiana	5	5	4	Green	Evergreen	Yes	Yes	19	Tall	13.5	Wide	1	60	5	5	5	5	3	**37**
3	Conifer Trees		Cupressus arizonica	5	5	4	Green	Evergreen	Yes	Yes	20	Tall	13.5	Wide	4	60	4	5	5	5	4	**37**
4	Conifer Trees		Cupressus torulosa	5	5	4	Yellow	Evergreen	Yes	No	17.5	Tall	9	Medium	4	27	3	5	5	5	5	**37**
5	Native Trees >15m		Eucalyptus baueriana (Eucalyptus bauerana)	5	5	4	Orange	Evergreen	Yes	No	17.5	Tall	15	Wide	1	60	5	4	5	5	4	**37**
6	Native Trees >15m		Eucalyptus melliodora	5	5	4	Yellow	Evergreen	Yes	Yes	22.5	Tall	20	Wide	1	106	5	5	5	5	3	**37**
7	Native Trees >15m		Eucalyptus melliodora (Tarcutta form)	5	5	4	Yellow	Evergreen	Yes	Yes	22.5	Tall	20	Wide	1	106	5	5	5	5	3	**37**
8	Native Trees >15m		Eucalyptus microcarpa (E. woollsiana)	5	4	4	Yellow	Evergreen	Yes	Yes	20	Tall	13.5	Wide	1	60	5	5	5	5	4	**37**
9	Native Trees >15m	New Species	Eucalyptus radiata	4	5	4	Orange	Evergreen	Yes	Yes	22.5	Very Tall	17.5	Wide	1	106	5	5	5	5	4	**37**
10	Native Trees >15m		Eucalyptus albens	4	5	4	Yellow	Evergreen	Yes	Yes	17.5	Tall	12.5	Wide	1	60	5	4	5	5	4	**36**
11	Native Trees 10-15m		Eucalyptus dealbata	4	5	4	No Data	Evergreen	Yes	Yes	12	Medium	8	Medium	1	17	5	5	5	5	3	**36**
14	Conifer Trees		Pinus pinea	5	5	4	Green	Evergreen	Yes	Yes	15	Medium	12	Wide	1	38	3	5	5	5	4	**36**
16	Native Trees >15m		Eucalyptus goniocalyx	4	5	4	orange	Evergreen	Yes	No	20	Tall	15	Wide	1	60	5	4	5	5	3	**35**
20	Introduced Trees 10-15m		Liquidambar styraciflua 'Palo Alto'	4	5	4	Green	Deciduous	Yes	Yes	13.5	Medium	12	Wide	4	38	5	5	5	3	4	**35**
21	Conifer Trees	New Species	Pinus eldarica	5	5	4	No Data	Evergreen	No	No	15	Tall	10	Medium	4	27	3	5	5	5	3	**35**
22	Introduced Trees <10m		Pistacia chinensis (P. sinensis) MALE CLONE ONLY	5	5	4	Green	Deciduous	Yes	Yes	9	Short	6	Medium	2	10	5	3	5	5	3	**35**
24	Introduced Trees 10-15m		Quercus ilex	4	5	4	Green	Evergreen	Yes	Yes	13.5	Medium	13.5	Wide	1	60	4	5	3	5	5	**35**
25	Introduced Trees >15m	New Species	Quercus lobata	4	5	4	Yellow	Deciduous	No	Yes	18	Tall	15	Wide	1	60	4	5	5	5	3	**35**
26	Introduced Trees >15m	New Species	Quercus macrocarpa	4	5	4	Orange	Deciduous	Yes	Yes	22.5	Tall	13.5	Wide	1	106	4	5	5	5	3	**35**
27	Native Trees 10-15m	New Species	Callitris glaucophylla	5	4	4	No Data	Evergreen	Yes	No	15	Medium	9	Medium	4	27	5	5	5	3	3	**34**
28	Conifer Trees		Cedrus atlantica 'Glauca'	5	4	4	Orange	Evergreen	Yes	Yes	20	Tall	17.5	Wide	4	106	3	5	5	5	3	**34**
35	Introduced Trees <10m	New Species	Lagerstroemia fauriei 'Kiowa'	4	5	4	Green	Deciduous	Yes	Yes	8	Short	8	Medium	3	17	5	3	5	5	3	**34**
36	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Osage'	4	5	4	Green	Deciduous	Yes	Yes	8	Short	8	Medium	5	17	5	3	5	5	3	**34**
37	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Biloxi'	4	5	4	Green	Deciduous	Yes	Yes	7	Short	5	Narrow	5	7	5	3	5	5	3	**34**
38	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Muskogee'	4	5	4	Green	Deciduous	Yes	Yes	6	Short	5	Narrow	5	7	5	3	5	5	3	**34**
39	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Natchez'	4	5	4	Green	Deciduous	Yes	Yes	8	Short	6	Medium	5	10	5	3	5	5	3	**34**
41	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Tuscarora'	4	5	4	Green	Deciduous	Yes	Yes	6	Short	4	Narrow	5	4	5	3	5	5	3	**34**
42	Introduced Trees 10-15m		Liquidambar styraciflua 'Tiriki'	4	5	4	Green	Deciduous	Yes	Yes	12	Medium	10	Medium	4	27	5	5	5	3	3	**34**
43	Native Trees <10m	New Species	Melia azedarach 'Elite'	5	4	4	Green	Deciduous	Yes	Yes	8	Short	9	Medium	2	21	4	3	5	5	4	**34**
44	Conifer Trees		Pinus sabiniana	4	5	4	No Data	Evergreen	Yes	Yes	15	Tall	10	Medium	4	27	3	5	5	5	3	**34**
45	Conifer Trees		Pinus torreyana	4	5	4	No Data	Evergreen	No	Yes	17.5	Tall	15	Wide	4	60	3	5	5	5	3	**34**
48	Introduced Trees 10-15m		Quercus suber	4	4	4	Green	Evergreen	No	Yes	15	Medium	15	Wide	1	60	4	5	3	5	5	**34**
49	Introduced Trees 10-15m	New Species	Ulmus parvifolia 'Emer II' Alee	4	4	4	Green	Deciduous	Yes	Yes	13	Medium	10	Medium	1	27	4	5	3	5	5	**34**
50	Native Trees <10m	New Species	Acacia pendula	5	4	4	Green	Evergreen	Yes	Yes	8	Short	5	Narrow	2	7	3	4	5	5	3	**33**
56	Introduced Trees <10m		Gleditsia triacanthos 'Sunburst'	4	5	4	Yellow	Deciduous	Yes	Yes	9	Short	9	Medium	2	27	5	4	3	5	3	**33**
59	Native Trees 10-15m	New Species	Melaleuca bracteata	4	4	4	No Data	Evergreen	Yes	No	10	Medium	7	Medium	1	17	4	3	5	5	4	**33**
79	Introduced Trees 10-15m		Gleditsia triacanthos 'Shademaster'	4	5	4	Yellow	Deciduous	Yes	Yes	11	Medium	12	Wide	1	38	5	3	3	5	3	**32**
80	Introduced Trees <10m		Laurus nobilis	4	5	4	No Data	Evergreen	Yes	Yes	6	Short	5	Narrow	2	7	3	3	5	5	3	**32**
81	Native Trees <10m	New Species	Melia azedarach 'Caroline'	5	4	4	Green	Deciduous	Yes	Yes	8	Short	7	Medium	2	13	4	3	3	5	4	**32**
82	Conifer Trees		Pinus halepensis	4	5	4	Green	Evergreen	Yes	Yes	17.5	Tall	12	Wide	4	38	3	5	3	5	3	**32**
86	Introduced Trees 10-15m	New Species	Quercus engelmannii	4	4	4	No Data	Evergreen	Yes	Yes	15	Medium	14	Wide	1	52	4	5	3	5	3	**32**
88	Conifer Trees		Taxodium distichum	5	4	4	No Data	Deciduous	Yes	No	20	Tall	10	Medium	4	27	5	5	3	3	3	**32**
101	Conifer Trees		Pinus canariensis	4	5	4	Green	Evergreen	Yes	Yes	25	Tall	15	Wide	4	60	3	4	3	5	3	**31**
105	Introduced Trees >15m	New Species	Populus deltoides 'Weetangera'	5	4	4	Yellow	Deciduous	Yes	Yes	20	Tall	15	Wide	1	60	4	3	3	5	3	**31**
106	Introduced Trees 10-15m	New Species	Pyrus calleryana 'Aristocrat'	5	4	4	Green	Deciduous	Yes	Yes	11	Medium	7	Medium	1	13	4	3	3	5	3	**31**
107	Introduced Trees 10-15m	New Species	Pyrus calleryana 'Chanticleer' syn. 'Cleveland Select'	5	4	4	Green	Deciduous	Yes	Yes	11	Medium	5.5	Medium	1	10	4	3	3	5	3	**31**
108	Introduced Trees 10-15m	New Species	Pyrus calleryana 'Red Spire'	5	4	4	Green	Deciduous	Yes	Yes	10	Medium	7	Medium	1	13	4	3	3	5	3	**31**
110	Introduced Trees 10-15m	New Species	Ulmus parvifolia 'Todd'	4	4	4	Green	Deciduous	Yes	Yes	10	Medium	11	Wide	1	32	4	3	3	5	4	**31**
121	Introduced Trees 10-15m	New Species	Fraxinus pennsylvanica 'Cimmzam' (Cimmaron)	4	4	4	Orange	Deciduous	Yes	Yes	11	Medium	9	Medium	4	27	4	3	5	3	3	**30**
122	Introduced Trees 10-15m	New Species	Fraxinus pennsylvanica 'Urbdell' (Urbanite)	4	4	4	Orange	Deciduous	Yes	Yes	12.5	Medium	9	Medium	4	27	4	3	5	3	3	**30**
123	Introduced Trees 10-15m	New Species	Fraxinus pennsylvanica 'Wasky' Skyward	4	4	4	Orange	Deciduous	Yes	Yes	10	Medium	6	Medium	4	10	4	3	5	3	3	**30**
124	Introduced Trees <10m		Koelreuteria paniculata	4	5	4	Yellow	Deciduous	Yes	Yes	8.5	Short	7	Medium	2	13	5	3	3	3	3	**30**

Genus: 22 Genera – Dominated by *Eucalyptus* (8), *Lagerstroemia* (6), *Pinus* (6), *Quercus* (4); **Species:** 52 Species; **Leaf Persistence:** 26 Deciduous 26 Evergreen; **MIS 25 History:** 26 new species; **Origin:** 37 introduced, 15 native; **Height:** 39 species over 10m, 13 species <10m; **Temperature Vulnerability:** 25 Green, 10 Yellow, 8 Orange, 9 No data

6.2.2. Low pedestrian traffic dryland grass or gravel

Table 12: Tree recommendations for low pedestrian traffic dryland grass or gravel.

Multi - Criteria Rank	Category	Restrictions	Species Name	Extreme Heat Tolerance	Drought Tolerance	Frost Tolerance	Temperature Vulnerability	Leaf Persistence	Commercially available?	Asset protection zone	Height	Height Descriptive	Width	Width Descriptive	Tree shape category	Available Soil Volume m3 Not less than	Potential as Allergen	Longevity	Weed Potential Score	Irrigation Score	Shade Type/ Density	Non Weighted Score (40)
1	Native Trees 10-15m	New Species	Brachychiton populneus	5	5	4	Green	Evergreen	Yes	Yes	11	Medium	9	Medium	1	27	5	5	5	5	3	**37**
2	Native Trees >15m		Casuarina cunninghamiana subsp. cunninghamiana	5	5	4	Green	Evergreen	Yes	Yes	19	Tall	13.5	Wide	1	60	5	5	5	5	3	**37**
3	Conifer Trees		Cupressus arizonica	5	5	4	Green	Evergreen	Yes	Yes	20	Tall	13.5	Wide	4	60	4	5	5	5	4	**37**
6	Native Trees >15m		Eucalyptus melliodora	5	5	4	Yellow	Evergreen	Yes	Yes	22.5	Tall	20	Wide	1	106	5	5	5	5	3	**37**
7	Native Trees >15m		Eucalyptus melliodora (Tarcutta form)	5	5	4	Yellow	Evergreen	Yes	Yes	22.5	Tall	20	Wide	1	106	5	5	5	5	3	**37**
8	Native Trees >15m		Eucalyptus microcarpa (E. woollsiana)	5	4	4	Yellow	Evergreen	Yes	Yes	20	Tall	13.5	Wide	1	60	5	5	5	5	4	**37**
9	Native Trees >15m	New Species	Eucalyptus radiata	4	5	4	Orange	Evergreen	Yes	Yes	22.5	Very Tall	17.5	Wide	1	106	5	5	5	5	4	**37**
10	Native Trees >15m		Eucalyptus albens	4	5	4	Yellow	Evergreen	Yes	Yes	17.5	Tall	12.5	Wide	1	60	5	4	5	5	4	**36**
11	Native Trees 10-15m		Eucalyptus dealbata	4	5	4	No Data	Evergreen	Yes	Yes	12	Medium	8	Medium	1	17	5	5	5	5	3	**36**
14	Conifer Trees		Pinus pinea	5	5	4	Green	Evergreen	Yes	Yes	15	Medium	12	Wide	1	38	3	5	5	5	4	**36**
17	Native Trees >15m		Eucalyptus polyanthemos subsp. polyanthemos	3	5	4	Yellow	Evergreen	Yes	Yes	20	Tall	15	Wide	1	60	5	5	5	5	3	**35**
22	Introduced Trees <10m		Pistacia chinensis (P. sinensis) MALE CLONE ONLY	5	5	4	Green	Deciduous	Yes	Yes	9	Short	6	Medium	2	10	5	3	5	5	3	**35**
24	Introduced Trees 10-15m		Quercus ilex	4	5	4	Green	Evergreen	Yes	Yes	13.5	Medium	13.5	Wide	1	60	4	5	3	5	5	**35**
25	Introduced Trees >15m	New Species	Quercus lobata	4	5	4	Yellow	Deciduous	No	Yes	18	Tall	15	Wide	1	60	4	5	5	5	3	**35**
26	Introduced Trees >15m	New Species	Quercus macrocarpa	4	5	4	Orange	Deciduous	Yes	Yes	22.5	Tall	13.5	Wide	1	106	4	5	5	5	3	**35**
28	Conifer Trees		Cedrus atlantica 'Glauca'	5	4	4	Orange	Evergreen	Yes	Yes	20	Tall	17.5	Wide	4	106	3	5	5	5	3	**34**
33	Native Trees >15m		Eucalyptus mannifera	3	5	4	Orange	Evergreen	Yes	Yes	20	Tall	13.5	Wide	1	60	5	4	5	5	3	**34**
34	Native Trees >15m		Eucalyptus rossii	3	4	4	Green	Evergreen	Yes	Yes	16.5	Medium	15	Wide	1	60	5	5	5	5	3	**34**
35	Introduced Trees <10m	New Species	Lagerstroemia fauriei 'Kiowa'	4	5	4	Green	Deciduous	Yes	Yes	8	Short	8	Medium	3	17	5	3	5	5	3	**34**
36	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Osage'	4	5	4	Green	Deciduous	Yes	Yes	8	Short	8	Medium	5	17	5	3	5	5	3	**34**
37	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Biloxi'	4	5	4	Green	Deciduous	Yes	Yes	7	Short	5	Narrow	5	7	5	3	5	5	3	**34**
38	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Muskogee'	4	5	4	Green	Deciduous	Yes	Yes	6	Short	5	Narrow	5	7	5	3	5	5	3	**34**
39	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Natchez'	4	5	4	Green	Deciduous	Yes	Yes	8	Short	6	Medium	5	10	5	3	5	5	3	**34**
40	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Sioux'	4	5	4	Green	Deciduous	Yes	Yes	5	Short	3	Narrow	5	2	5	3	5	5	3	**34**
41	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Tuscarora'	4	5	4	Green	Deciduous	Yes	Yes	6	Short	4	Narrow	5	4	5	3	5	5	3	**34**
43	Native Trees <10m	New Species	Melia azedarach 'Elite'	5	4	4	Green	Deciduous	Yes	Yes	8	Short	9	Medium	2	21	4	3	5	5	4	**34**
44	Conifer Trees		Pinus sabiniana	4	5	4	No Data	Evergreen	Yes	Yes	15	Tall	10	Medium	4	27	3	5	5	5	3	**34**
45	Conifer Trees		Pinus torreyana	4	5	4	No Data	Evergreen	No	Yes	17.5	Tall	15	Wide	4	60	3	5	5	5	3	**34**
46	Introduced Trees 10-15m	New Species	Quercus douglasii	3	5	4	Yellow	Deciduous	No	Yes	15	Medium	12	Wide	1	38	4	5	3	5	5	**34**
47	Introduced Trees >15m		Quercus palustris 'Free Fall'	3	4	4	Orange	Deciduous	Yes	Yes	18	Tall	15	Wide	1	60	4	5	5	5	4	**34**
48	Introduced Trees 10-15m		Quercus suber	4	4	4	Green	Evergreen	No	Yes	15	Medium	15	Wide	1	60	4	5	3	5	5	**34**
49	Introduced Trees 10-15m	New Species	Ulmus parvifolia 'Emer II' Alee	4	4	4	Green	Deciduous	Yes	Yes	13	Medium	10	Medium	1	27	4	5	3	5	5	**34**
50	Native Trees <10m	New Species	Acacia pendula	5	4	4	Green	Evergreen	Yes	Yes	8	Short	5	Narrow	2	7	3	4	5	5	3	**33**
56	Introduced Trees <10m		Gleditsia triacanthos 'Sunburst'	4	5	4	Yellow	Deciduous	Yes	Yes	9	Short	9	Medium	2	27	5	4	3	5	3	**33**
65	Introduced Trees >15m		Quercus palustris	3	4	4	Orange	Deciduous	Yes	Yes	18	Tall	13.5	Wide	1	60	4	5	5	5	3	**33**
67	Introduced Trees 10-15m		Quercus robur 'Fastigiata'	3	4	4	Orange	Deciduous	Yes	Yes	13.5	Medium	6	Medium	3	10	4	5	5	5	3	**33**
79	Introduced Trees 10-15m		Gleditsia triacanthos 'Shademaster'	4	5	4	Yellow	Deciduous	Yes	Yes	11	Medium	12	Wide	1	38	5	3	3	5	3	**32**
80	Introduced Trees <10m		Laurus nobilis	4	5	4	No Data	Evergreen	Yes	Yes	6	Short	5	Narrow	2	7	3	3	5	5	3	**32**
81	Native Trees <10m	New Species	Melia azedarach 'Caroline'	5	4	4	Green	Deciduous	Yes	Yes	8	Short	7	Medium	2	13	4	3	3	5	4	**32**
82	Conifer Trees		Pinus halepensis	4	5	4	Green	Evergreen	Yes	Yes	17.5	Tall	12	Wide	4	38	3	5	3	5	3	**32**
84	Introduced Trees 10-15m		Populus simonii	3	4	4	Orange	Deciduous	Yes	Yes	15	Medium	4.5	Narrow	1	60	4	4	5	5	3	**32**
86	Introduced Trees 10-15m	New Species	Quercus engelmannii	4	4	4	No Data	Evergreen	Yes	Yes	15	Medium	14	Wide	1	52	4	5	3	5	3	**32**
91	Conifer Trees		Cedrus deodara	3	3	4	Yellow	Evergreen	Yes	Yes	20	Tall	17.5	Wide	4	106	3	5	5	5	3	**31**
98	Introduced Trees 10-15m		Fraxinus angustifolia subsp. oxycarpa 'Raywood'	3	4	4	Orange	Deciduous	Yes	Yes	15	Medium	13.5	Wide	1	60	4	4	3	5	4	**31**
99	Introduced Trees 10-15m	New Species	Fraxinus excelsior 'Westhof's Glorie' (F. velutina rootstock)	3	3	4	No Data	Deciduous	Yes	Yes	15	Medium	8	Medium	1	17	4	4	5	5	3	**31**
101	Conifer Trees		Pinus canariensis	4	5	4	Green	Evergreen	Yes	Yes	25	Tall	15	Wide	4	60	3	4	3	5	3	**31**
102	Conifer Trees		Pinus patula	3	5	4	Yellow	Evergreen	Yes	Yes	15	Tall	10	Medium	4	27	3	5	3	5	3	**31**
105	Introduced Trees >15m	New Species	Populus deltoides 'Weetangera'	5	4	4	Yellow	Deciduous	Yes	Yes	20	Tall	15	Wide	1	60	4	3	3	5	3	**31**
106	Introduced Trees 10-15m	New Species	Pyrus calleryana 'Aristocrat'	5	4	4	Green	Deciduous	Yes	Yes	11	Medium	7	Medium	1	13	4	3	3	5	3	**31**
107	Introduced Trees 10-15m	New Species	Pyrus calleryana 'Chanticleer' syn. 'Cleveland Select'	5	4	4	Green	Deciduous	Yes	Yes	11	Medium	5.5	Medium	1	10	4	3	3	5	3	**31**
108	Introduced Trees 10-15m	New Species	Pyrus calleryana 'Red Spire'	5	4	4	Green	Deciduous	Yes	Yes	10	Medium	7	Medium	1	13	4	3	3	5	3	**31**
110	Introduced Trees 10-15m	New Species	Ulmus parvifolia 'Todd'	4	4	4	Green	Deciduous	Yes	Yes	10	Medium	11	Wide	1	32	4	3	3	5	4	**31**
128	Introduced Trees <10m		Prunus cerasifera 'Nigra'	3	4	4	Yellow	Deciduous	Yes	Yes	6	Short	5	Narrow	2	7	5	3	3	5	3	**30**
135	Introduced Trees <10m	New Species	Arbutus menziesii	3	4	3	No Data	Evergreen	Yes	Yes	8	Short	6	Medium	2	10	3	5	3	5	3	**29**
147	Introduced Trees 10-15m	New Species	Populus x canescens 'Tower'	3	4	4	Red	Deciduous	Yes	Yes	15	Medium	3	Narrow	3	60	4	3	3	5	3	**29**
160	Introduced Trees <10m		Arbutus unedo	3	4	4	Yellow	Evergreen	Yes	Yes	5	Short	4	Narrow	2	4	3	3	3	5	3	**28**

Genus: 19 Genera – Dominated by *Eucalyptus* (9), *Quercus* (9), *Lagerstroemia* (7), *Pinus* (6); **Species:** 56 Species; **Leaf Persistence:** 29 Deciduous, 27 Evergreen; **MIS 25 history:** 25 new species; **Origin:** 42 introduced, 14 native; **Height:** 40 species over 10m, 16 species <10m; **Temperature Vulnerability:** 25 Green, 14 Yellow, 9 Orange, 1 Red, 7 No Data

6.2.3. Irrigated grass conditions

Table 13: Tree recommendations for irrigated grass conditions

Multi - Criteria Rank	Category	Restrictions	Species Name	Extreme Heat Tolerance	Drought Tolerance	Frost Tolerance	Temperature Vulnerability	Leaf Persistence	Commercially available?	Asset protection zone	Height	Height Descriptive	Width	Width Descriptive	Tree shape category	Available Soil Volume m3 Not less than	Potential as Allergen	Longevity	Weed Potential Score	Irrigation Score	Shade Type/ Density	Non Weighted Score (40)
57	Introduced Trees >15m		Liquidambar styraciflua	4	3	4	Green	Deciduous	Yes	Yes	17.5	Tall	12	Wide	4	38	5	5	5	3	4	**33**
58	Introduced Trees >15m		Liquidambar styraciflua 'Festeri'	4	3	4	Green	Deciduous	Yes	Yes	20	Tall	12	Wide	4	38	5	5	5	3	4	**33**
96	Introduced Trees 10-15m	New Species	Fagus sylvatica 'Purpurea'	2	3	4	No Data	Deciduous	Yes	Yes	12	Medium	8	Medium	1	17	5	5	5	3	4	**31**
97	Introduced Trees 10-15m	New Species	Fraxinus americana	4	3	4	Yellow	Deciduous	Yes	Yes	15	Tall	12	Wide	1	38	4	5	5	3	3	**31**
100	Introduced Trees 10-15m	Special Plant	Ginkgo biloba	3	3	4	Yellow	Deciduous	Yes	Yes	15	Tall	10	Medium	1	38	5	5	5	3	3	**31**
119	Native Trees 10-15m	Special Plant	Eucalyptus pauciflora subsp. Pauciflora (E. pauciflora)	3	3	5	Orange	Evergreen	Yes	Yes	15	Medium	10	Medium	1	27	5	4	5	3	2	**30**
120	Native Trees >15m		Eucalyptus rubida subsp. Rubida	2	3	4	Orange	Evergreen	Yes	Yes	16.5	Medium	12.5	Wide	1	60	5	5	5	3	3	**30**
132	Introduced Trees >15m	Special Plant	Ulmus americana	4	3	4	Yellow	Deciduous	Yes	Yes	20	Tall	15	Wide	5	60	4	5	3	3	4	**30**
134	Native Trees >15m	Special Plant	Araucaria bidwillii	2	3	4	No Data	Evergreen	Yes	Yes	22.5	Tall	15	Wide	4	60	5	3	5	3	4	**29**
142	Introduced Trees 10-15m		Fraxinus velutina	5	3	3	Green	Deciduous	Yes	Yes	11	Medium	10	Medium	1	27	4	3	5	3	3	**29**
150	Introduced Trees 10-15m		Quercus acutissima	2	3	4	Yellow	Deciduous	Yes	Yes	15	Medium	15	Wide	1	60	4	5	5	3	3	**29**
152	Introduced Trees >15m		Quercus robur	3	3	4	Orange	Deciduous	Yes	Yes	20	Tall	22.5	Wide	1	166	4	5	3	3	4	**29**
156	Introduced Trees <10m	New Species	Acer palmatum 'Trompenburg'	2	3	4	Orange	Deciduous	Yes	Yes	5	Short	5	Narrow	2	7	5	3	5	3	3	**28**
158	Introduced Trees <10m	New Species	Acer rubrum 'October Glory'	2	3	4	Orange	Deciduous	Yes	Yes	9	Short	5	Narrow	3	7	5	3	5	3	3	**28**
165	Introduced Trees 10-15m		Fraxinus ornus	3	3	4	Orange	Deciduous	Yes	Yes	11	Medium	10	Medium	1	27	4	5	3	3	3	**28**
167	Introduced Trees <10m		Malus floribunda	2	3	4	Red	Deciduous	Yes	Yes	5	Short	5	Narrow	2	7	5	3	5	3	3	**28**
169	Introduced Trees <10m	New Species	Malus x purpurea	2	3	4	No Data	Deciduous	Yes	Yes	7	Short	5	Narrow	2	7	5	3	5	3	3	**28**
173	Introduced Trees 10-15m		Ulmus parvifolia 'Yarralumla Clone'	4	3	4	Green	Deciduous	Yes	Yes	15	Medium	13.5	Wide	1	60	4	4	3	3	3	**28**
174	Introduced Trees >15m	Special Plant	Ulmus procera	2	2	4	No Data	Deciduous	Yes	Yes	27.5	Very Tall	19	Wide	1	106	4	5	3	3	5	**28**
175	Introduced Trees 10-15m		Zelkova serrata	2	3	4	Green	Deciduous	Yes	Yes	13.5	Medium	11	Wide	1	38	5	3	5	3	3	**28**
176	Native Trees 10-15m	New Species	Acacia caerulescens	3	3	4	No Data	Evergreen	No	Yes	12.5	Medium	7	Medium	1	13	3	3	5	3	3	**27**
181	Introduced Trees <10m	New Species	Arbutus andrachne	3	3	4	No Data	Evergreen	No	Yes	8	Short	7	Medium	2	13	3	5	3	3	3	**27**
184	Introduced Trees <10m		Prunus cerasifera 'Pissardii'	3	3	4	Yellow	Deciduous	Yes	Yes	6	Short	4	Narrow	2	4	5	3	3	3	3	**27**
185	Introduced Trees <10m		Prunus persica	3	3	4	Green	Deciduous	Yes	Yes	5	Short	5	Narrow	2	7	5	3	3	3	3	**27**
190	Introduced Trees <10m		Fraxinus excelsior 'Aurea Pendula'	3	2	4	No Data	Deciduous	Yes	Yes	7	Short	8	Medium	2	17	4	4	5	1	3	**26**
191	Introduced Trees 10-15m		Fraxinus excelsior 'Aurea'	3	2	4	No Data	Deciduous	Yes	Yes	11	Medium	9	Medium	2	27	4	4	5	1	3	**26**
193	Introduced Trees <10m	New Species	Prunus cerasifera 'Oakville Crimson Spire'	3	3	4	Yellow	Deciduous	Yes	Yes	6	Short	2	Narrow	3	10	5	3	3	3	2	**26**

Genus: 14 Genera – Dominated by *Fraxinus* (5), *Prunus* (3), *Ulmus* (3); **Species:** 27 Species; **Leaf Persistence:** 22 Deciduous, 5 Evergreen; **MIS 25 history:** 8 new species, 5 special plants; **Origin:** 23 introduced, 4 native; **Height:** 18 species over 10m, 9 species <10m; **Temperature Vulnerability:** 6 Green, 6 Yellow, 6 Orange, 1 Red, 8 No Data

6.2.4. Lanes and Narrow verges

Table 14: Tree recommendations for lanes and narrow verges

Multi - Criteria Rank	Category	Restrictions	Species Name	Extreme Heat Tolerance	Drought Tolerance	Frost Tolerance	Temperature Vulnerability	Leaf Persistence	Commercially available?	Asset protection zone	Height	Height Descriptive	Width	Width Descriptive	Tree shape category	Available Soil Volume m3 Not less than	Potential as Allergen	Longevity	Weed Potential Score	Irrigation Score	Shade Type/ Density	Non Weighted Score (40)
22	Introduced Trees <10m		Pistacia chinensis (P. sinensis) MALE CLONE ONLY	5	5	4	Green	Deciduous	Yes	Yes	9	Short	6	Medium	2	10	5	3	5	5	3	**35**
37	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Biloxi'	4	5	4	Green	Deciduous	Yes	Yes	7	Short	5	Narrow	5	7	5	3	5	5	3	**34**
38	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Muskogee'	4	5	4	Green	Deciduous	Yes	Yes	6	Short	5	Narrow	5	7	5	3	5	5	3	**34**
39	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Natchez'	4	5	4	Green	Deciduous	Yes	Yes	8	Short	6	Medium	5	10	5	3	5	5	3	**34**
40	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Sioux'	4	5	4	Green	Deciduous	Yes	Yes	5	Short	3	Narrow	5	2	5	3	5	5	3	**34**
41	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Tuscarora'	4	5	4	Green	Deciduous	Yes	Yes	6	Short	4	Narrow	5	4	5	3	5	5	3	**34**
50	Native Trees <10m	New Species	Acacia pendula	5	4	4	Green	Evergreen	Yes	Yes	8	Short	5	Narrow	2	7	3	4	5	5	3	**33**
67	Introduced Trees 10-15m		Quercus robur 'Fastigiata'	3	4	4	Orange	Deciduous	Yes	Yes	13.5	Medium	6	Medium	3	10	4	5	5	5	3	**33**
80	Introduced Trees <10m		Laurus nobilis	4	5	4	No Data	Evergreen	Yes	Yes	6	Short	5	Narrow	2	7	3	3	5	5	3	**32**
107	Introduced Trees 10-15m	New Species	Pyrus calleryana 'Chanticleer' syn. 'Cleveland Select'	5	4	4	Green	Deciduous	Yes	Yes	11	Medium	5.5	Medium	1	10	4	3	3	5	3	**31**
128	Introduced Trees <10m		Prunus cerasifera 'Nigra'	3	4	4	Yellow	Deciduous	Yes	Yes	6	Short	5	Narrow	2	7	5	3	3	5	3	**30**
135	Introduced Trees <10m	New Species	Arbutus menziesii	3	4	3	No Data	Evergreen	Yes	Yes	8	Short	6	Medium	2	10	3	5	3	5	3	**29**
160	Introduced Trees <10m		Arbutus unedo	3	4	4	Yellow	Evergreen	Yes	Yes	5	Short	4	Narrow	2	4	3	3	3	5	3	**28**

Genus: 8 Genera – Dominated by *Lagerstroemia* (5), *Arbutus* (2); **Species:** 13 Species; **Leaf Persistence:** 9 Deciduous, 4 Evergreen; **MIS 25 history:** 8 new species; **Origin:** 12 introduced, 1 native; **Height:** 2 species over 10m, 11 species <10m; **Temperature Vulnerability:** 8 Green, 2 Yellow, 1 Orange, 2 No Data

6.2.5. Local and collector streets

Table 15: Tree recommendations for local and collector streets

Multi - Criteria Rank	Category	Restrictions	Species Name	Extreme Heat Tolerance	Drought Tolerance	Frost Tolerance	Temperature Vulnerability	Leaf Persistence	Commercially available?	Asset protection zone	Height	Height Descriptive	Width	Width Descriptive	Tree shape category	Available Soil Volume m3 Not less than	Potential as Allergen	Longevity	Weed Potential Score	Irrigation Score	Shade Type/ Density	Non Weighted Score (40)
1	Native Trees 10-15m	New Species	Brachychiton populneus	5	5	4	Green	Evergreen	Yes	Yes	11	Medium	9	Medium	1	27	5	5	5	5	3	**37**
2	Native Trees >15m		Casuarina cunninghamiana subsp. cunninghamiana	5	5	4	Green	Evergreen	Yes	Yes	19	Tall	13.5	Wide	1	60	5	5	5	5	3	**37**
3	Conifer Trees		Cupressus arizonica	5	5	4	Green	Evergreen	Yes	Yes	20	Tall	13.5	Wide	4	60	4	5	5	5	4	**37**
8	Native Trees >15m		Eucalyptus microcarpa (E. woollsiana)	5	4	4	Yellow	Evergreen	Yes	Yes	20	Tall	13.5	Wide	1	60	5	5	5	5	4	**37**
10	Native Trees >15m		Eucalyptus albens	4	5	4	Yellow	Evergreen	Yes	Yes	17.5	Tall	12.5	Wide	1	60	5	4	5	5	4	**36**
11	Native Trees 10-15m		Eucalyptus dealbata	4	5	4	No Data	Evergreen	Yes	Yes	12	Medium	8	Medium	1	17	5	5	5	5	3	**36**
14	Conifer Trees		Pinus pinea	5	5	4	Green	Evergreen	Yes	Yes	15	Medium	12	Wide	1	38	3	5	5	5	4	**36**
17	Native Trees >15m		Eucalyptus polyanthemos subsp. polyanthemos	3	5	4	Yellow	Evergreen	Yes	Yes	20	Tall	15	Wide	1	60	5	5	5	5	3	**35**
22	Introduced Trees <10m		Pistacia chinensis (P. sinensis) MALE CLONE ONLY	5	5	4	Green	Deciduous	Yes	Yes	9	Short	6	Medium	2	10	5	3	5	5	3	**35**
24	Introduced Trees 10-15m		Quercus ilex	4	5	4	Green	Evergreen	Yes	Yes	13.5	Medium	13.5	Wide	1	60	4	5	3	5	5	**35**
25	Introduced Trees >15m	New Species	Quercus lobata	4	5	4	Yellow	Deciduous	No	Yes	18	Tall	15	Wide	1	60	4	5	5	5	3	**35**
33	Native Trees >15m		Eucalyptus mannifera	3	5	4	Orange	Evergreen	Yes	Yes	20	Tall	13.5	Wide	1	60	5	4	5	5	3	**34**
34	Native Trees >15m		Eucalyptus rossii	3	4	4	Green	Evergreen	Yes	Yes	16.5	Medium	15	Wide	1	60	5	5	5	5	3	**34**
35	Introduced Trees <10m	New Species	Lagerstroemia fauriei 'Kiowa'	4	5	4	Green	Deciduous	Yes	Yes	8	Short	8	Medium	3	17	5	3	5	5	3	**34**
36	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Osage'	4	5	4	Green	Deciduous	Yes	Yes	8	Short	8	Medium	5	17	5	3	5	5	3	**34**
37	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Biloxi'	4	5	4	Green	Deciduous	Yes	Yes	7	Short	5	Narrow	5	7	5	3	5	5	3	**34**
38	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Muskogee'	4	5	4	Green	Deciduous	Yes	Yes	6	Short	5	Narrow	5	7	5	3	5	5	3	**34**
39	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Natchez'	4	5	4	Green	Deciduous	Yes	Yes	8	Short	6	Medium	5	10	5	3	5	5	3	**34**
40	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Sioux'	4	5	4	Green	Deciduous	Yes	Yes	5	Short	3	Narrow	5	2	5	3	5	5	3	**34**
41	Introduced Trees <10m	New Species	Lagerstroemia x L. fauriei 'Tuscarora'	4	5	4	Green	Deciduous	Yes	Yes	6	Short	4	Narrow	5	4	5	3	5	5	3	**34**
43	Native Trees <10m	New Species	Melia azedarach 'Elite'	5	4	4	Green	Deciduous	Yes	Yes	8	Short	9	Medium	2	21	4	3	5	5	4	**34**
44	Conifer Trees		Pinus sabiniana	4	5	4	No Data	Evergreen	Yes	Yes	15	Tall	10	Medium	4	27	3	5	5	5	3	**34**
45	Conifer Trees		Pinus torreyana	4	5	4	No Data	Evergreen	No	Yes	17.5	Tall	15	Wide	4	60	3	5	5	5	3	**34**
46	Introduced Trees 10-15m	New Species	Quercus douglasii	3	5	4	Yellow	Deciduous	No	Yes	15	Medium	12	Wide	1	38	4	5	3	5	5	**34**
47	Introduced Trees >15m		Quercus palustris 'Free Fall'	3	4	4	Orange	Deciduous	Yes	Yes	18	Tall	15	Wide	1	60	4	5	5	5	4	**34**
48	Introduced Trees 10-15m		Quercus suber	4	4	4	Green	Evergreen	No	Yes	15	Medium	15	Wide	1	60	4	5	3	5	5	**34**
49	Introduced Trees 10-15m	New Species	Ulmus parvifolia 'Emer II' Alee	4	4	4	Green	Deciduous	Yes	Yes	13	Medium	10	Medium	1	27	4	5	3	5	5	**34**
50	Native Trees <10m	New Species	Acacia pendula	5	4	4	Green	Evergreen	Yes	Yes	8	Short	5	Narrow	2	7	3	4	5	5	3	**33**
56	Introduced Trees <10m		Gleditsia triacanthos 'Sunburst'	4	5	4	Yellow	Deciduous	Yes	Yes	9	Short	9	Medium	2	27	5	4	3	5	3	**33**
65	Introduced Trees >15m		Quercus palustris	3	4	4	Orange	Deciduous	Yes	Yes	18	Tall	13.5	Wide	1	60	4	5	5	5	3	**33**
67	Introduced Trees 10-15m		Quercus robur 'Fastigiata'	3	4	4	Orange	Deciduous	Yes	Yes	13.5	Medium	6	Medium	3	10	4	5	5	5	3	**33**
79	Introduced Trees 10-15m		Gleditsia triacanthos 'Shademaster'	4	5	4	Yellow	Deciduous	Yes	Yes	11	Medium	12	Wide	1	38	5	3	3	5	3	**32**
80	Introduced Trees <10m		Laurus nobilis	4	5	4	No Data	Evergreen	Yes	Yes	6	Short	5	Narrow	2	7	3	3	5	5	3	**32**
81	Native Trees <10m	New Species	Melia azedarach 'Caroline'	5	4	4	Green	Deciduous	Yes	Yes	8	Short	7	Medium	2	13	4	3	3	5	4	**32**
82	Conifer Trees		Pinus halepensis	4	5	4	Green	Evergreen	Yes	Yes	17.5	Tall	12	Wide	4	38	3	5	3	5	3	**32**
84	Introduced Trees 10-15m		Populus simonii	3	4	4	Orange	Deciduous	Yes	Yes	15	Medium	4.5	Narrow	1	60	4	4	5	5	3	**32**
86	Introduced Trees 10-15m	New Species	Quercus engelmannii	4	4	4	No Data	Evergreen	Yes	Yes	15	Medium	14	Wide	1	52	4	5	3	5	3	**32**
98	Introduced Trees 10-15m		Fraxinus angustifolia subsp. oxycarpa 'Raywood'	3	4	4	Orange	Deciduous	Yes	Yes	15	Medium	13.5	Wide	1	60	4	4	3	5	4	**31**
99	Introduced Trees 10-15m	New Species	Fraxinus excelsior 'Westhof's Glorie' (F. velutina rootstock)	3	3	4	No Data	Deciduous	Yes	Yes	15	Medium	8	Medium	1	17	4	4	5	5	3	**31**
101	Conifer Trees		Pinus canariensis	4	5	4	Green	Evergreen	Yes	Yes	25	Tall	15	Wide	4	60	3	4	3	5	3	**31**
102	Conifer Trees		Pinus patula	3	5	4	Yellow	Evergreen	Yes	Yes	15	Tall	10	Medium	4	27	3	5	3	5	3	**31**
105	Introduced Trees >15m	New Species	Populus deltoides 'Weetangera'	5	4	4	Yellow	Deciduous	Yes	Yes	20	Tall	15	Wide	1	60	4	3	3	5	3	**31**
106	Introduced Trees 10-15m	New Species	Pyrus calleryana 'Aristocrat'	5	4	4	Green	Deciduous	Yes	Yes	11	Medium	7	Medium	1	13	4	3	3	5	3	**31**
107	Introduced Trees 10-15m	New Species	Pyrus calleryana 'Chanticleer' syn. 'Cleveland Select'	5	4	4	Green	Deciduous	Yes	Yes	11	Medium	5.5	Medium	1	10	4	3	3	5	3	**31**
108	Introduced Trees 10-15m	New Species	Pyrus calleryana 'Red Spire'	5	4	4	Green	Deciduous	Yes	Yes	10	Medium	7	Medium	1	13	4	3	3	5	3	**31**
110	Introduced Trees 10-15m	New Species	Ulmus parvifolia 'Todd'	4	4	4	Green	Deciduous	Yes	Yes	10	Medium	11	Wide	1	32	4	3	3	5	4	**31**
128	Introduced Trees <10m		Prunus cerasifera 'Nigra'	3	4	4	Yellow	Deciduous	Yes	Yes	6	Short	5	Narrow	2	7	5	3	3	5	3	**30**
135	Introduced Trees <10m	New Species	Arbutus menziesii	3	4	3	No Data	Evergreen	Yes	Yes	8	Short	6	Medium	2	10	3	5	3	5	3	**29**
147	Introduced Trees 10-15m	New Species	Populus x canescens 'Tower'	3	4	4	Red	Deciduous	Yes	Yes	15	Medium	3	Narrow	3	60	4	3	3	5	3	**29**
160	Introduced Trees <10m		Arbutus unedo	3	4	4	Yellow	Evergreen	Yes	Yes	5	Short	4	Narrow	2	4	3	3	3	5	3	**28**

Genus: 18 Genera – Dominated by *Quercus* (8), *Lagerstroemia* (7), *Eucalyptus* (6), *Pinus* (6); **Species:** 50 Species; **Leaf Persistence:** 28 Deciduous, 22 Evergreen; **MIS 25 history:** 23 new species; **Origin:** 39 introduced, 11 native; **Height:** 34 species over 10m, 16 species <10m; **Temperature Vulnerability:** 25 Green, 11 Yellow, 6 Orange, 1 Red, 7 No data

6.2.6. Avenues and arterials roads

Table 16: Tree recommendations for avenues and arterial roads

Multi - Criteria Rank	Category	Restrictions	Species Name	Extreme Heat Tolerance	Drought Tolerance	Frost Tolerance	Temperature Vulnerability	Leaf Persistence	Commercially available?	Asset protection zone	Height	Height Descriptive	Width	Width Descriptive	Tree shape category	Available Soil Volume m3 Not less than	Potential as Allergen	Longevity	Weed Potential Score	Irrigation Score	Shade Type/ Density	Non Weighted Score (40)
1	Native Trees 10-15m	New Species	Brachychiton populneus	5	5	4	Green	Evergreen	Yes	Yes	11	Medium	9	Medium	1	27	5	5	5	5	3	**37**
2	Native Trees >15m		Casuarina cunninghamiana subsp. cunninghamiana	5	5	4	Green	Evergreen	Yes	Yes	19	Tall	13.5	Wide	1	60	5	5	5	5	3	**37**
3	Conifer Trees		Cupressus arizonica	5	5	4	Green	Evergreen	Yes	Yes	20	Tall	13.5	Wide	4	60	4	5	5	5	4	**37**
6	Native Trees >15m		Eucalyptus melliodora	5	5	4	Yellow	Evergreen	Yes	Yes	22.5	Tall	20	Wide	1	106	5	5	5	5	3	**37**
7	Native Trees >15m		Eucalyptus melliodora (Tarcutta form)	5	5	4	Yellow	Evergreen	Yes	Yes	22.5	Tall	20	Wide	1	106	5	5	5	5	3	**37**
8	Native Trees >15m		Eucalyptus microcarpa (E. woollsiana)	5	4	4	Yellow	Evergreen	Yes	Yes	20	Tall	13.5	Wide	1	60	5	5	5	5	4	**37**
9	Native Trees >15m	New Species	Eucalyptus radiata	4	5	4	Orange	Evergreen	Yes	Yes	22.5	Very Tall	17.5	Wide	1	106	5	5	5	5	4	**37**
10	Native Trees >15m		Eucalyptus albens	4	5	4	Yellow	Evergreen	Yes	Yes	17.5	Tall	12.5	Wide	1	60	5	4	5	5	4	**36**
11	Native Trees 10-15m		Eucalyptus dealbata	4	5	4	No Data	Evergreen	Yes	Yes	12	Medium	8	Medium	1	17	5	5	5	5	3	**36**
14	Conifer Trees		Pinus pinea	5	5	4	Green	Evergreen	Yes	Yes	15	Medium	12	Wide	1	38	3	5	5	5	4	**36**
17	Native Trees >15m		Eucalyptus polyanthemos subsp. polyanthemos	3	5	4	Yellow	Evergreen	Yes	Yes	20	Tall	15	Wide	1	60	5	5	5	5	3	**35**
24	Introduced Trees 10-15m		Quercus ilex	4	5	4	Green	Evergreen	Yes	Yes	13.5	Medium	13.5	Wide	1	60	4	5	3	5	5	**35**
25	Introduced Trees >15m	New Species	Quercus lobata	4	5	4	Yellow	Deciduous	No	Yes	18	Tall	15	Wide	1	60	4	5	5	5	3	**35**
26	Introduced Trees >15m	New Species	Quercus macrocarpa	4	5	4	Orange	Deciduous	Yes	Yes	22.5	Tall	13.5	Wide	1	106	4	5	5	5	3	**35**
28	Conifer Trees		Cedrus atlantica 'Glauca'	5	4	4	Orange	Evergreen	Yes	Yes	20	Tall	17.5	Wide	4	106	3	5	5	5	3	**34**
33	Native Trees >15m		Eucalyptus mannifera	3	5	4	Orange	Evergreen	Yes	Yes	20	Tall	13.5	Wide	1	60	5	4	5	5	3	**34**
34	Native Trees >15m		Eucalyptus rossii	3	4	4	Green	Evergreen	Yes	Yes	16.5	Medium	15	Wide	1	60	5	5	5	5	3	**34**
44	Conifer Trees		Pinus sabiniana	4	5	4	No Data	Evergreen	Yes	Yes	15	Tall	10	Medium	4	27	3	5	5	5	3	**34**
45	Conifer Trees		Pinus torreyana	4	5	4	No Data	Evergreen	No	Yes	17.5	Tall	15	Wide	4	60	3	5	5	5	3	**34**
46	Introduced Trees 10-15m	New Species	Quercus douglasii	3	5	4	Yellow	Deciduous	No	Yes	15	Medium	12	Wide	1	38	4	5	3	5	5	**34**
47	Introduced Trees >15m		Quercus palustris 'Free Fall'	3	4	4	Orange	Deciduous	Yes	Yes	18	Tall	15	Wide	1	60	4	5	5	5	4	**34**
48	Introduced Trees 10-15m		Quercus suber	4	4	4	Green	Evergreen	No	Yes	15	Medium	15	Wide	1	60	4	5	3	5	5	**34**
49	Introduced Trees 10-15m	New Species	Ulmus parvifolia 'Emer II' Alee	4	4	4	Green	Deciduous	Yes	Yes	13	Medium	10	Medium	1	27	4	5	3	5	5	**34**
65	Introduced Trees >15m		Quercus palustris	3	4	4	Orange	Deciduous	Yes	Yes	18	Tall	13.5	Wide	1	60	4	5	5	5	3	**33**
67	Introduced Trees 10-15m		Quercus robur 'Fastigiata'	3	4	4	Orange	Deciduous	Yes	Yes	13.5	Medium	6	Medium	3	10	4	5	5	5	3	**33**
79	Introduced Trees 10-15m		Gleditsia triacanthos 'Shademaster'	4	5	4	Yellow	Deciduous	Yes	Yes	11	Medium	12	Wide	1	38	5	3	3	5	3	**32**
82	Conifer Trees		Pinus halepensis	4	5	4	Green	Evergreen	Yes	Yes	17.5	Tall	12	Wide	4	38	3	5	3	5	3	**32**
84	Introduced Trees 10-15m		Populus simonii	3	4	4	Orange	Deciduous	Yes	Yes	15	Medium	4.5	Narrow	1	60	4	4	5	5	3	**32**
86	Introduced Trees 10-15m	New Species	Quercus engelmannii	4	4	4	No Data	Evergreen	Yes	Yes	15	Medium	14	Wide	1	52	4	5	3	5	3	**32**
91	Conifer Trees		Cedrus deodara	3	3	4	Yellow	Evergreen	Yes	Yes	20	Tall	17.5	Wide	4	106	3	5	5	5	3	**31**
98	Introduced Trees 10-15m		Fraxinus angustifolia subsp. oxycarpa 'Raywood'	3	4	4	Orange	Deciduous	Yes	Yes	15	Medium	13.5	Wide	1	60	4	4	3	5	4	**31**
99	Introduced Trees 10-15m	New Species	Fraxinus excelsior 'Westhof's Glorie' (F. velutina rootstock)	3	3	4	No Data	Deciduous	Yes	Yes	15	Medium	8	Medium	1	17	4	4	5	5	3	**31**
101	Conifer Trees		Pinus canariensis	4	5	4	Green	Evergreen	Yes	Yes	25	Tall	15	Wide	4	60	3	4	3	5	3	**31**
102	Conifer Trees		Pinus patula	3	5	4	Yellow	Evergreen	Yes	Yes	15	Tall	10	Medium	4	27	3	5	3	5	3	**31**
105	Introduced Trees >15m	New Species	Populus deltoides 'Weetangera'	5	4	4	Yellow	Deciduous	Yes	Yes	20	Tall	15	Wide	1	60	4	3	3	5	3	**31**
106	Introduced Trees 10-15m	New Species	Pyrus calleryana 'Aristocrat'	5	4	4	Green	Deciduous	Yes	Yes	11	Medium	7	Medium	1	13	4	3	3	5	3	**31**
107	Introduced Trees 10-15m	New Species	Pyrus calleryana 'Chanticleer' syn. 'Cleveland Select'	5	4	4	Green	Deciduous	Yes	Yes	11	Medium	5.5	Medium	1	10	4	3	3	5	3	**31**
108	Introduced Trees 10-15m	New Species	Pyrus calleryana 'Red Spire'	5	4	4	Green	Deciduous	Yes	Yes	10	Medium	7	Medium	1	13	4	3	3	5	3	**31**
110	Introduced Trees 10-15m	New Species	Ulmus parvifolia 'Todd'	4	4	4	Green	Deciduous	Yes	Yes	10	Medium	11	Wide	1	32	4	3	3	5	4	**31**
147	Introduced Trees 10-15m	New Species	Populus x canescens 'Tower'	3	4	4	Red	Deciduous	Yes	Yes	15	Medium	3	Narrow	3	60	4	3	3	5	3	**29**

Genus: 12 Genera – Dominated by *Eucalyptus* (9), *Quercus* (9), *Pinus* (6); **Species:** 40 Species; **Leaf Persistence**: 17 Deciduous, 23 Evergreen; **MIS 25 history:** 14 new species; **Origin:** 20 introduced, 11 native; **Height:** 40 species over 10m;

Temperature Vulnerability: 14 Green, 11 Yellow, 9 Orange, 1 Red, 5 No data

The high pedestrian and low pedestrian scenarios recommendations were very similar. The only difference was that it was assumed a higher extreme heat tolerance score was needed for high pedestrian areas due to radiant heat from surrounding infrastructure. Both scenarios were approximately 50/50 deciduous and evergreen, <70% introduced and had <70% species over 10m.

The irrigated grassland scenario recommendations were completely different to the low and high pedestrian scenarios due to the assumptions made about due to better water availability. This scenario included more considerably more deciduous (80%) and introduced (85%) trees, however species over 10m (66%) were still highly represented.

The narrow street, local street and avenues scenarios were all similar to the low pedestrian scenario in terms of assumptions, although limitations on space, both above and below ground, differentiated the lists. The local streets scenario was by far the most comparable to the low pedestrian scenario.

6.2.7. New species

The MIS 25 tree species list is a diverse list of species applicable for a wide variety of applications and scenarios. It is clear that it has been shaped and crafted over many years and therefore there no trees that are entirely unsuitable to Canberra's conditions. For example, there are no species on the list that are not tolerant to frost or drought as those are relatively common occurrences in Canberra.

While the MIS 25 is a noteworthy list, it is important be acknowledge that new species, not yet on the list and not yet planted in Canberra, might also be well suited to Canberra's climate change future. After consultation with Albury- Wodonga, Condobolin, Dubbo, Forbes, Griffith, Parkes, West Wyalong, Wagga Wagga, Wangaratta local councils, and the National Arboretum Canberra a number of species have suggested for addition to the list. Each suggested species was reviewed using the criteria matrix and ranked. Table 17 outlines the suggested species for addition into the MIS 25.

Many of the councils had similar tree species and lists to the MIS 25, however from personal communication the councils, supplemental irrigation is commonly used in these smaller towns to mitigate water availability issues. Given that these smaller towns have significantly smaller urban forests estates (e.g. Wagga Wagga has 66,000) in comparison to Canberra, irrigation across the entire Canberra estate is unfeasible.

Despite being suggestions, *Cupressus dupreziana, Eucalyptus camaldulensis, and Betula pendula subsp. fontqueri* do not appear in any scenarios. Six out of the 11 (54%) suggested species appear in the top 50 ranked species. There are 4 suggested species at also occur in the National Arboretum Canberra.

Table 17: List of recommended new species for the MIS 25, including species name, common name, potential multi-criteria rank, which scenario the species would be included in and comments about species.

Species	Common Name	Potential Multi Criteria Rank	Scenario inclusion	Comment
Cupressus dupreziana	Saharan Cypress	14	-	Forest 40 in National Arboretum Canberra and are very health specimens. Excluded from most scenarios due to APZ incompatibility. This needs to be confirmed.
Corymbia citriodora	Lemon Scented Gum	26	High Pedestrian, Low Pedestrian, Local streets, Avenues	Restricted natural range but planted widely in urban areas in Victoria and NSW (2.2% of City of Melbourne, 0.97% of City of Sydney, 2.9% of Shepparton)
Corymbia maculata	Spotted Gum	26	High Pedestrian, Low Pedestrian, Local streets, Avenues	Restricted natural range but planted widely in urban areas in Victoria and NSW. Slightly more vulnerable to temperature increase than *Corymbia citriodora* Kendal (et al 2017)
Eucalyptus camaldulensis	River Red Gum	26	-	One of Australia's most widespread eucalypts, anecdotal evidence suggest that it has been difficult to establish in Canberra. Excluded from most scenarios due to APZ incompatibility and moderate drought tolerance.
Cupaniopsis anacardioides	Carrot wood / Tuckeroo	26	High Pedestrian, Low Pedestrian, Local streets	Possible issues with large fruit – Species makes up 2.44% of City of Sydney, 1.46% of Marrickville and 1.55% of Burnsides (Adelaide) street trees.
Lophostemon confertus	Queensland Brush Box	50	Low Pedestrian, Local streets, Avenues	Prized as a street tree, it is a hardy tree that is rarely troubled by pests or diseases. It tolerates smog, drought, heavy pruning and poor drainage.[12]
Albizia julibrissin	Persian silk tree	68	Low Pedestrian, Narrow lanes and verges, Local streets	Forest 6 in National Arboretum Canberra. Significant beetle/ cockatoo damage in this forest, May be a good candidate for short lived nurse tree. It was listed in a Department of the Interior Publication in 1968 named "Ten Trees for Canberra Gardens".
Geijera parviflora	Wilga / Native Willow	88	Low Pedestrian, Narrow lanes and verges, Local streets	The market does not produce many seedlings because it is extremely difficult to germinate from seed, and cutting propagation is unreliable[13]. They are only tolerant of 1–18 frosts per year, otherwise they are extremely drought and temperature tolerant.

[12] https://www.gardeningwithangus.com.au/lophostemon-confertus-queensland-brush-box/
[13] https://metrotrees.com.au/geijera-parviflora/

Species	Common Name	Potential Multi Criteria Rank	Scenario inclusion	Comment
Grevillea robusta	Silky Oak	113	High Pedestrian, Low Pedestrian, Local streets, Avenues	Forest 51 in the National Arboretum Canberra. One of the most popular ornamental native trees in Australia. They are widely grown in Australia and also overseas as shade-trees and for their ability to adapt.[14]
Jacaranda mimosifolia	Jacaranda	133	High Pedestrian	Jacarandas planted in Parkes, Dubbo, and Griffith. Jacarandas are frost tender when young but tolerate frost better once it grows above three metres in height. If they get a run of heavy frosts they can get frost burn, but they generally recover[15]. It does not appear in many scenarios due to moderate need for irrigation.
Betula pendula Subsp. fontqueri	Spanish Birch	154	-	Forest 44 in the National Arboretum Canberra. Good across all criteria, except for potential allergen (score 1). Much better scores in climate variables than Europe Birch

[14] https://www.gardeningwithangus.com.au/grevillea-robusta-silky-oak/
[15] https://www.dailyliberal.com.au/story/1891536/gallery-dubbos-heart-bursting-into-spring-flower/

7. Discussion

7.1. Top 50 species

The intention of the top 50 ranking method was to rank the best all-round urban trees. By scoring the trees across all criteria, it was possible to identify species or genera that are most suitable for Canberra urban forest, taking into account climate factors, allergen information, weed potential and tree characteristic. The scoring and ranking methodology allows analysis of the trends and patterns across genera and species.

It is clear that both introduced and native species, especially eucalyptus, are suitable for Canberra's Climate Change future. This is not surprising considering the genus is native to the region and represents 20% of the TCCS MIS 25 species.

Although leaf persistence in the top 50 is skewed towards evergreen due to the number of Eucalyptus and conifers represented, deciduous trees are also represented and are suitable Canberra's climate change future. Conversely, deciduous introduced species from make up the majority of species in the bottom 50. A significant proportion are *Prunus* and *Acer*, both of which have many varieties/cultivars in the MIS 25. Despite this, *Prunus campanulata* and *Prunus mume* both scored "green" for their temperature vulnerability and 1 in extreme temperature tolerance. Strangely this suggests that they are not considered vulnerable to increase in temperature but would suffer in extreme temperatures. In interesting conundrum.

The top/bottom 50 species rankings are is an interesting visualisation tool to observe the 'best' and 'worst' all round species across all criteria. The intention of the multi-criteria matrix is to sort trees according to all of their traits and tolerances, however after careful analysis it is clear that low or lower scores in even one criteria can play a large role in reducing a species rank or potential suitability for particular scenarios. Accordingly, these rankings must be viewed with an element of caution. The ranks are a guide and should be viewed with reference to the individual criteria rather than in isolation. For example, two trees might have the same scores in climate-based criteria and the other criteria, but have a difference of 2 point in a criteria (e.g. weediness). In this case the difference between the two species might be 2 points as one is moderately weedy and the other has low weediness.

These 2 points might mean the difference between a top 50 tree (*Acacia Pendula* – score 33) and a ranking of 108 (*Pyrus calleryana* 'Red Spire' – Score 31). Both species are equally as robust in their response to climate change, however a 2-point difference in weediness significantly affects the ranking of *Pyrus calleryana* 'Red Spire'.

Although the temperature vulnerability data is not used in the scoring of the species, it is clear that species that score highly in the criteria matrix correspond to species that are less vulnerability to temperature increase. Almost half of the top 50 species are considered to have no risk to increasing temperature and there are no high-risk species in the top 50. In contrast, the bottom 50 species only has 6 species that are considered no risk and 5 high-risk species. Unfortunately, 22 of the species in the bottom 50 and 10 species in the top 50 have no data. It would have been wonderful to use the temperature vulnerability data in the multi criteria matrix, however it is valuable for validating where possible the species in the top 50 and scenarios.

7.2. Pollen and Potential allergens

Platanus orientalis ranked 94 (score 31). It scored High (4) in all climate criteria and moderate to high (score 3-5) in all the other criteria, however it scored poorly as a potential allergen (1). *Platanus orientalis* did not rank in the top 50 or in any of the scenarios due to its allergen potential. This raises the question as to the respiratory effects of urban forest allergens and external allergen sources. For example, it may be important to view the allergenic potential of the urban forest in the context of non-forest allergens sources such as rye grass from surrounding grasslands (ASCIA, 2017) and agricultural areas. According to Kendal (2017) and analysis of the climate criteria in this study, *Platanus orientalis* is not vulnerable to temperature increase, and is tolerant of extreme heat, drought and frost. The analysis shows it would survive and thrive in Canberra's projected climate change scenarios and provide good summer cooling, although it may contribute to allergenic load.

Some studies suggest *Platanus* pollen may not be as associated with hay fever symptoms as first though, however, the study was not conclusive and also suggested *Platanus* leaf trichomes may be a respiratory irritant (Sercombe et al, 2011). Other studies state that Platanus pollen is an important cause of pollenosis but also showed that grasses were an important source of allergens (Varela et al. 1997).

Despite the inconclusively that *Platanus* genra are a major allergen, the recommendation from Pollen expert Simon Haberle is to restrict planting of species that score 1 and 2 in potential pollen allergies, this includes *Platanus orientalis* and its varieties.

Pazouki et al. (2008), states that the reactive components of *Platanus orientalis* pollen showed a higher level of cross-reactivity with *Platanus occidentalis* pollen in comparison with *Platanus acerifolia* pollen. In additionally, the allergen for *Platanus orientalis* could be species specific (Pazouki et al. 2008). This could mean, *Platanus acerifolia* may present a reduced risk as a potential allergen than other *Platanus* species, however this is by no means confirmed.

7.3. Scenarios

During the data analysis for the scenarios, it became evident that generating a representative 'top 10' for each scenario was challenging without knowing more detail about the scenario details. It is simple enough to analyse and filter the multi-criteria matrix based on specific undesirable attributes for that scenario, however, by generating a 'top 10', there is considerable risk that the list will not be representative of the range of species (deciduous or evergreen, tall or short, wide or narrow) that are suitable for various incarnations of particular scenarios.

In the case for high pedestrian traffic pavements with strata cells, the top 10 species consist of 7 *Eucalyptus* and 2 *Cupressus*. Considering the scenario, recommending 7 *Eucalyptus* and 2 *Cupressus* is not very helpful, even though they would survive and thrive in this scenario. Providing a larger list with more diversity, allows for some discretionary decision making depending on the scenario particulars. As a result, all scenarios consisted of significantly more than 10 species (between 13 and 56 species) and consisted of species ranked between 1 and 193.

Given that best practices suggests no single species in an urban forest should be more than 5% of the trees, it is prudent to suggest at least 20 species. In addition, there are suggestions that no single genus should represent more than 30-40% of the urban forest. The City of Melbourne is taking this one step further. They are propose no more than 5% of any one species, no more than 10% of any one genus, and no more than 20% of any one family (City of Melbourne, 2011).

It is also important to recognise that the analysis is based on the current data available and makes assumptions based on each scenario. These assumptions have been made in consultation with the project committee and are intended to reflect the limitations and/or opportunities for species in each scenario but may not necessarily accurate for all iterations of each scenario. The exciting thing about the criteria matrix is that end users can easily use it to sort and filter the species to identify a range of the most suitable species for real world scenarios. In additional, new species can be entered into the criteria matrix and can quickly and easily be scored and ranked to determine their suitability in Canberra's urban forest in to the future.

7.4. New Species

A number of the suggested species, particularly *Corymbia citriodora* and *Corymbia maculata,* ranked very well in the criteria matrix and were present in many of the scenarios. Conversely, a number of species ranked well (*Eucalyptus camaldulensis* and *Cupressus dupreziana*) but did not present in any of the scenarios, primarily due to their incompatibility with the APZ.

The suggestion of *Betula pendula Subsp. Fontqueri* was with the knowledge that it would be excluded from all the scenarios due to its potential allergen score. Despite this, it does score well in the all other variable and could be considered a species for special locations where it is not planted in residential areas and not en masse.

The suggestion of *Jacaranda mimosifolia* is an ambitious one. Data suggests it is drought tolerant and extreme heat tolerant however it needs moderate irrigation. This fact rules it out of most scenarios. In addition, it is not very frost hardy despite growing in other inland areas that experience heavy frosts. Although, Jacaranda ranks in the middle of the MIS 25, it may be worth a try in particular areas, most due to the fact that it grows well in areas, such as Dubbo and Parkes, which are locations Canberra climate is expected mirror in the future.

7.5. Other recommendations and considerations

When recommending trees that are suitable for Canberra's climate change future, there are many other factors that contribute to the health and survival of an individual trees and an urban forest other than the species. It is critical that these trees are given the best possible chance to survive and thrive. Considering the vulnerable situation of urban trees, it is important to use every opportunity to improve the growing environment of these trees (City of Stockholm, 2009). This means providing trees with suitable growing conditions such as adequate soil volume, lack of soil compaction and soil moisture availability. Essentially, we can't just plant the right tree in the right place, we must also consider more solutions to create the right place for the right tree (Deeproot, 2013). There are a number of strategies to improve conditions for urban trees. These include infrastructure and water sensitive urban design, soil technologies, planting structure and design, and provenance.

7.5.1. Infrastructure and Water Sensitive Urban Design (WSUD)

Rainfall and storm water is a resource. Urban infrastructure is often not conductive to water infiltration. It is designed to efficiently divert water into stormwater drains where it immediately becomes unavailable to trees. This allows for little to no infiltration (Figure 4). Innovative design and engineering of infrastructure with water sensitive design and technology can provide urban trees substantially more access to rainwater that traditional infrastructure. There are a number of design methods to slow water movement offsite and improve water infiltration in urban areas. These include:

- Passive Stormwater harvesting systems (LOCI, 2017) such as Smart soaker (2014) direct storm water into sub soil through storm water diversion (pits, channels, trenches, holes) at the storm water drain entry. These pits then recharge the ground water and passively irrigate surrounding urban trees.
- Porous and permeable pavements are alternatives to paved surfaces that allow fluids (stormwater and runoff) to flow through it into the ground/soil profile below. This allows ground water to be recharged more effectively.
- Green swale / bio swale is a long, channelled depression or trench that is designed to slow and filter stormwater and runoff from large impervious areas.

Figure 23: Example of Green swales and bioswales (Soils.org, 2018), (SCTC, 2018)

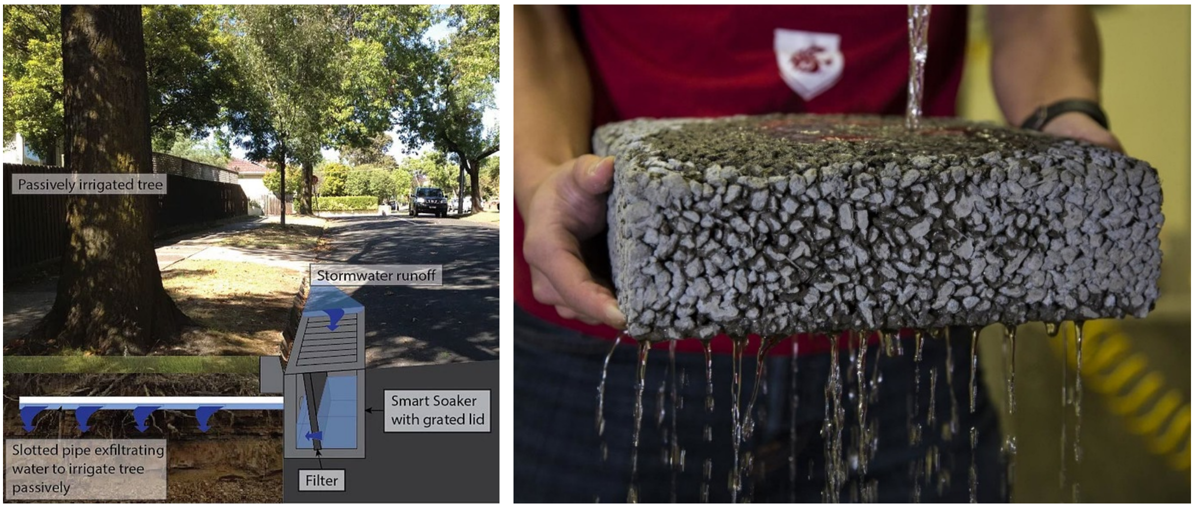


Figure 24: Diagram of stormwater pits and passive urban tree irrigation (smartsoaker, 2014); permeable paving material (phys.org, 2018)

It is critically important that trees are able to utilise every available drop of water for them to survive and thrive in Canberra's climate change future. Development approval should consider targets or compulsory implementation of water sensitive urban infrastructure.

7.5.2. Soil

Soil is the growing medium for trees and gives then foundation and stability. Although not all soils are conducive to the growth of plants and trees, especially in an urban landscape.

Trees are often are planted in restricted planting pits with poor subsoil, resulting in reduced growth. Urban landscapes are characterised by pave surfaces. Paved surfaces require solid, compacted ground for pedestrian movement and vehicular traffic which is not favourable to tree growth or health. Frequently, trees, in the search for resources (nutrients, water, and space), cause structural pavement damage. The challenge in urban landscapes is maintaining soil structure for trees while also providing solid structural component for paved surface. Two solutions to this challenge include; Structural soils and Strata[16]/Silva[17] cells.

- Structural soils/Stockholm soils. A soil is constructed using a rock matrix (80%) as its structural component and soil or biochar (20%) as the growing medium. The intention that the rock matrix will physically support the pavement while the soil and biochar with sustain the tree (Figure 25).

Figure 25: Urban tree root growth in structural soils (University of Florida, 2015; ASCS, 2013)

- Strata/Silva Cells are a modular high density plastic structures that assemble into a skeletal matrix provides a structural support for pavement loading while providing large volume of soil within the structure.

[16] https://citygreen.com/product-category/soil-structure-systems/
[17] https://www.deeproot.com/products/silva-cell.html

Figure 26: Example of strata cells in urban landscapes (Outdoor Design, 2013; Willerby landscapes, 2018; GreenBlue Urban, 2016)

Various studies compare these two techniques with regards to available soil volume, tree health and growth, ease of implementation, design and cost. Both techniques have their advantages and disadvantages that need to be weighted up when deciding which technique is most suitable in particular scenarios.

7.5.3. Planting Structure and Design

7.5.3.1. Nurse trees

A nurse tree is a larger, faster-growing tree that fosters the growth of another smaller, slower-growing tree or plant. A nurse tree can provide shade, shelter from wind, or protection from animals who would feed on the smaller plant. Fast growing, short lived species such as Acacias and Albizia can be used as nurse trees to shade, shelter and create a more habitable micro climate for slower growing, longer lived trees species during their establishment. As fast growing species populate/occupy site space quickly, they can also rapidly improve site aesthetics and provide shade in a short period of time. Once these nurse species have reached their lifespan generally between 5-15 years, they can be removed leaving the healthy, established slower growing, longer lived tree urban tree.

7.5.3.2. Tree Banking

There is potential to pre-grow trial species in the National Arboretum Canberra (ANU Research Forest 101)[18]. This would be a fantastic opportunity to trial new species, flag establishment issues grow and potentially grow trees ahead of new developments or in preparation for tree replacement. This would provide opportunities for diversifying age classes and providing advanced trees for immediate greening.

Figure 27: Example of transplanting established trees from one site to another using a tree spade (ArborCoAustralia, 2012)

7.5.3.3. Parallel planting

There is potentially a large benefit from planting young, replacement trees near the aging trees a number of years prior to their removal. By the time of removal, the replacement trees will have already grown considerably, reducing the visual loss when the old trees are finally removed (Hitchmough 1990). There are a variety of different urban forestry regime

[18] Contact Owen Bolitho, Senior Horticulturalist and Matthew Parker, Operations Manager at the National Arboretum Canberra for more details.

strategies based on rotation length, removal time and replacement strategy which impact on aesthetic value (Figure 28). These include;

a) Single landscape rotations – maintaining the tree for as long as possible, or until death
b) Single landscape rotations – replacing when the tree enters decline;
c) Dual landscape rotations – plant replacement tree next to declining tree a number of years before removal; and
d) Continuous landscape rotations – continually planting replacement trees.

It is clear that loss of aesthetic value is minimised when implementing strategies that are proactive in tree removal and replacement. These strategies also have the potential to increase species and age class diversity in an urban forest.

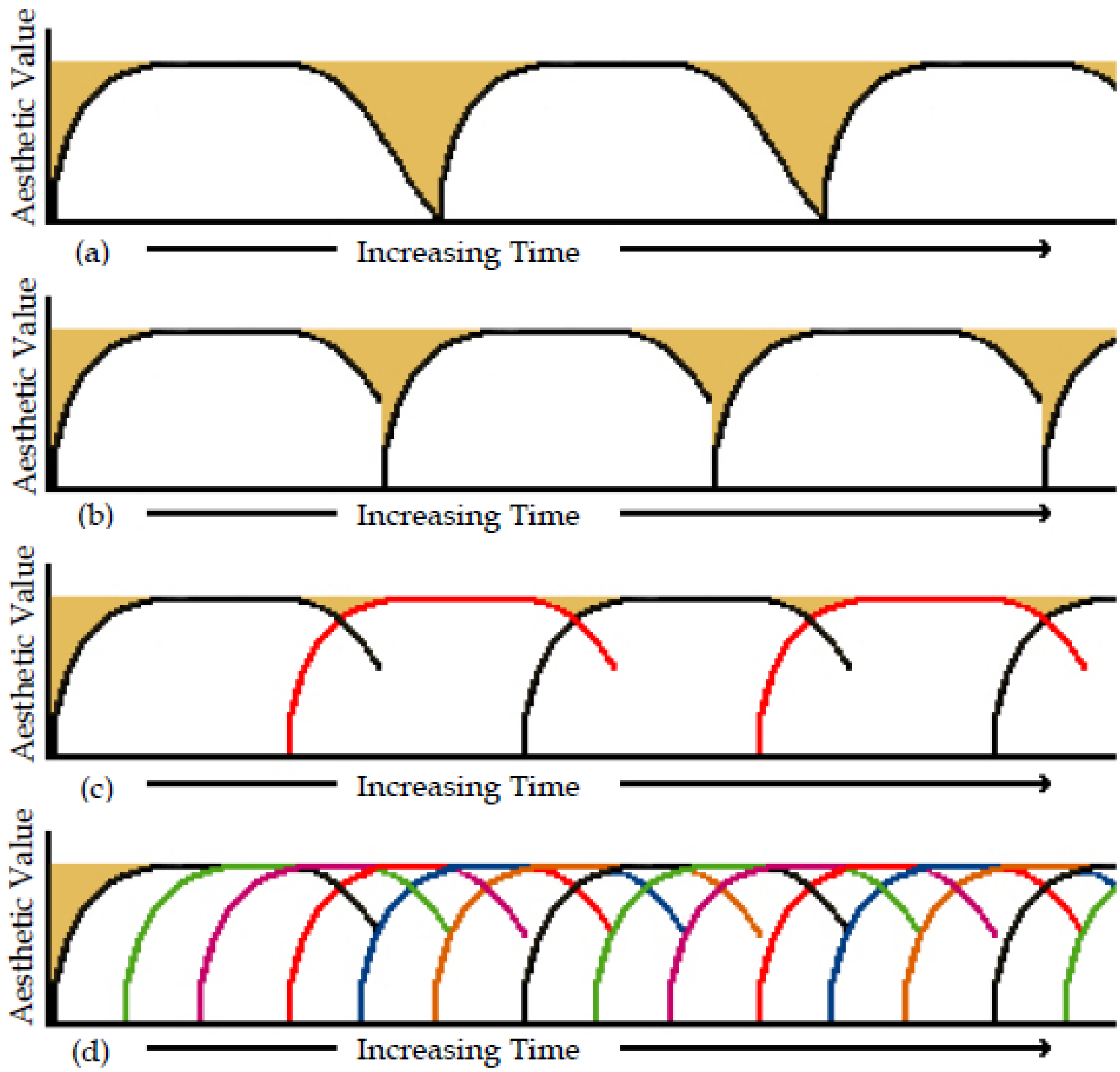


Figure 28: Model of changes in the aesthetic value of a single tree or group of trees under different replacement regimes. (a) Single landscape rotations – maintaining the tree for as long as possible, or until death (b) single landscape rotations – replacing when the tree enters decline; (c) dual landscape rotations – plant replacement tree next to declining tree a number of years before removal; and (d) continuous landscape rotations – continually planting replacement trees. The shaded area highlights the time and aesthetic value lost when trees are removed and replaced. (Parker, 2004) Adapted from Cobham (1984, p.12) and Hitchmough (1994a, p.270).

7.5.3.4. Mixed species and mixed structure

Structure, age class and species diversity are important for an urban forestry not only for aesthetics but for the health of the forest. Urban forests with low species and age class diversity are potentially at greater risk from extreme events such as drought and climate change, the urban heat island effect and disease and pest outbreaks than more diverse urban forests (City of Melbourne 2011; Kendal, et al. 2014; Alvey 2006).

Although urban forest with low species diversity are more vulnerable to biotic and abiotic stresses, greater species diversity does not necessarily translate to greater resilience to future changes in urban climate in Australia. Species selection based on resilience and responses to biotic and abiotic conditions is also critically important. (City of Melbourne 2011), which is the primary purpose for this study.

Best practices urban forest species diversity suggests the 10-20-30 rule of thumb; not more than 10% (and more recently 5% (City of Melbourne, 2011)) of any one species, not more than 20% of any one genus, not more than 30% of any one family, and no single species (Santamour, 1990). Kendal et al. (2014) more recently suggests that benchmarks such as this may need to be lowered in urban forests that span multiple land uses and temperature climates to be effective. These types of benchmarks are important but species diversity and tree spacing along streets and suburbs is important (Figure 29). Tree planting design can impact solar access (minimal shading for photovoltaic panels) in residential areas, aesthetics, pavement shading and maintenance scheduling.

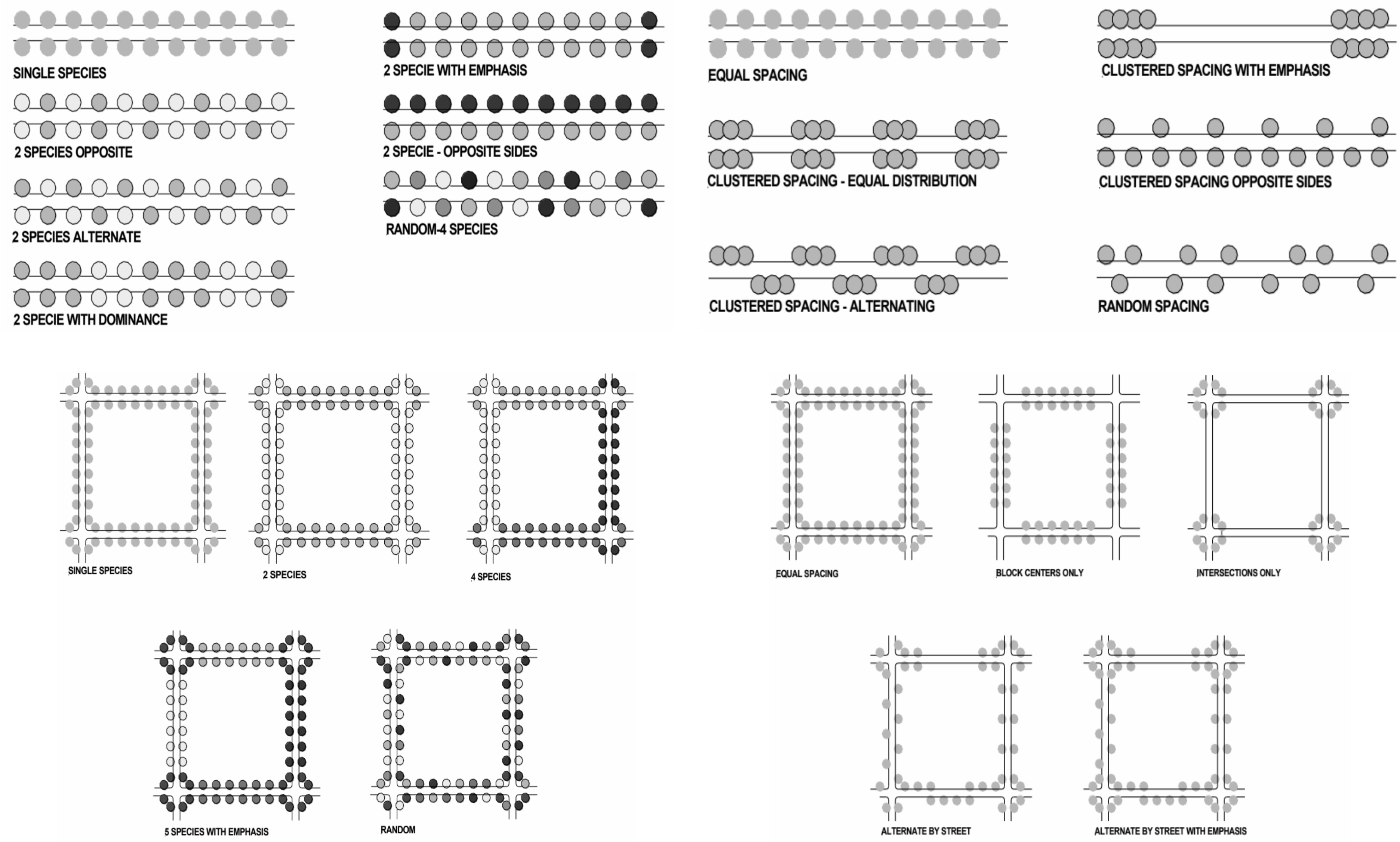


Figure 29: Examples of mixed species and spacing strategies at street and block scale (Green 2018).

7.5.3.5. Structure

Structure is defined as the horizontal and vertical distribution of layers in a forest including the biodiversity of trees (proportion of small, medium and large), shrubs, and ground cover (Bennett 2010). It is generally overlooked in urban forestry as healthy, large, prominent, shady street trees are the norm. Increasing diversity of lifeforms, tree size and creating layers of vegetation improves flora and fauna biodiversity, increases habitat opportunities, increases surface shading and can improve aesthetics (Figure 30, Figure *31*).

Figure 30: Before and after understory planting in Marrickville council (Inner West Council, 2018)

Figure 31: Examples of structure in local collector streets (Saving our Trees 2012; Hahn, 2014)

7.5.3.6. Provenance

When species have a wide distribution, choose provenances that reflect Canberra climate change future, i.e. hotter and dryer. For example, *Bachychiton populneus*, attempt to use seeds and nursery stock from provenances from areas west of Canberra with hotter dryer climates such as Griffith or Condobolin (Figure 32). That said, caution must also be taken when introducing new provenances to the region that could breed with surrounding trees of the same species.

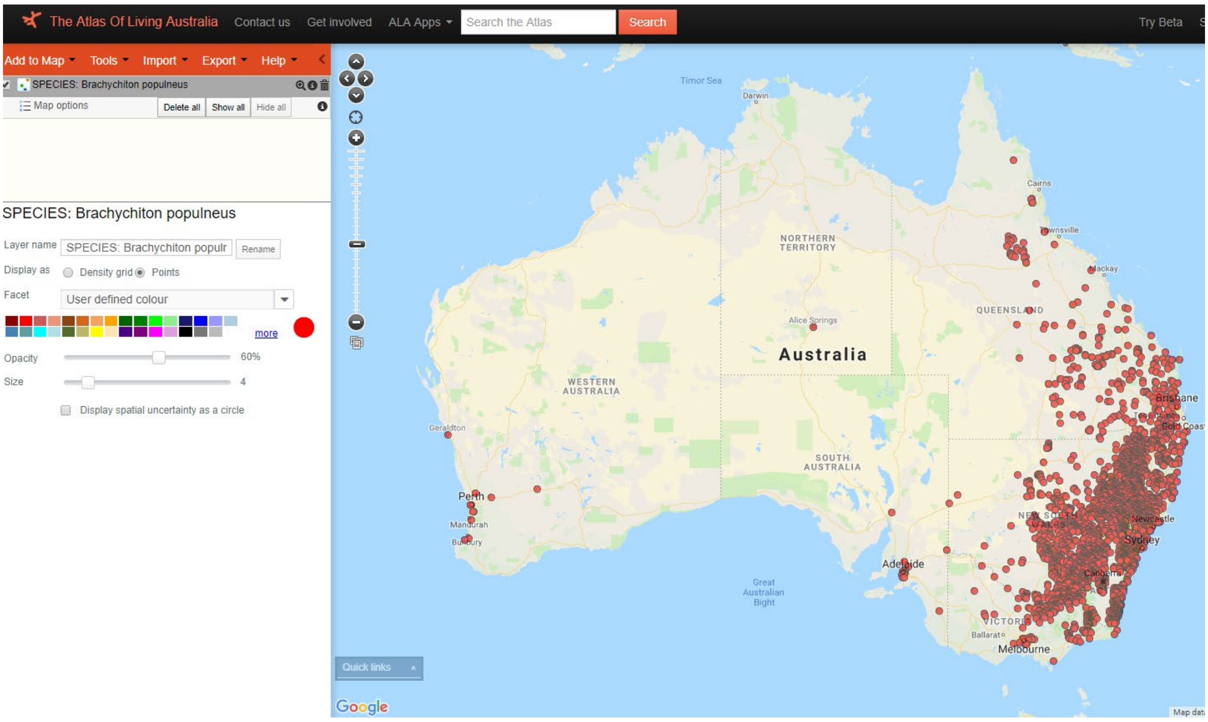


Figure 32: Distribution of Bachychiton populneus using Atlas of Living Australia (ALA 2018).

8. Conclusion:

The age-old urban forestry saying states that there is no perfect street tree, but that one must plant 'the right tree in the right place'. Yet, what is right tree is and what is the right place, and what will that place be like in the future? This research endeavoured to outline Canberra's future climatic conditions and identify which species will survive and thrive in these. We have advised on which species would be more suited to particular scenarios and suggested a number of new species that could be added to the already comprehensive MIS 25 species list.

In recommending which tree species are suitable for Canberra's climate change future, it became increasing apparent that urban environments are hostile to trees and limit trees' access to two fundamental requirements - water and soil. Choosing the right tree for the right place is one thing, but what if one can manipulate the place to make it more suitable for the tree also. This report has also outlined a number of strategies to create more hospitable environments and improve the relationship between urban infrastructure and urban trees.

9. Further Research

- Responses of individual tree species to extreme heat, increased annual temperatures increases and elevated CO_2. There is potentially a partnership opportunity with Dave Ellsworth from the Which Plant Where - https://www.whichplantwhere.com.au/ project.
- Detailed modelling of shade cast by tree species to determine the best summer time cooling species, given that the hottest part of the day (and potentially peak energy demand time) is the early to mid-afternoon (3 – 4:30pm) when the angle of the sun is more horizontal. Trees with vertical hanging leaves (*Eucalyptus*) might provide more useful shade for cooling than initially thought.
- Potential allergens and impacts on respiratory health of urban dwellers. What is the effect of grasslands and other external allergen sources on Canberra's respiratory health? Is excluding high potential allergen tree species an appropriate mitigation strategy or do external allergen sources have a disproportionate effect that outweighs allergens from the urban forest? Could these species still be planted individually or in small groups?

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11. Appendix 1

Table 18: List of information sources for species-level data in multi-criteria matrix

Source	Type	Website
National Herbarium of NSW, Royal Botanic Garden Sydney	Government	http://plantnet.rbgsyd.nsw.gov.au/
EUCLID Eucalypts of Australia	Not for profit	http://keyserver.lucidcentral.org:8080/euclid/keys.jsp
Atlas of living Australia	Not for profit	https://www.ala.org.au/
Florabank - Greening Australia	Not for profit	http://www.florabank.org.au/
Centre for Agriculture and Biosciences International - Invasive Species Compendium	Not for profit	https://www.cabi.org/ISC/
Botanic Gardens of South Australia - Plant Selector	Government	http://plantselector.botanicgardens.sa.gov.au/
The Australian National Botanic Gardens - Centre for Australian National Biodiversity Research (CANBR)	Government	https://www.anbg.gov.au/index.html
The Australian Plants Society - NSW	Not for profit	https://austplants.com.au/
Australian Plants Online	Nursery	http://www.australianplantsonline.com.au/
Fire Effects Information System (FEIS) - United States Department of Agriculture	Government	https://www.feis-crs.org/feis/
Burkes Backyard	Private business	https://www.burkesbackyard.com.au/
Metro trees	Nursery	https://metrotrees.com.au/
The Gymnosperm Database	Not for profit	https://www.conifers.org/index.php
National Arboretum Canberra	Government	https://www.nationalarboretum.act.gov.au/home
Office of Environment and Heritage NSW	Government	https://www.environment.nsw.gov.au/topics/animals-and-plants/threatened-species
Provincial Plants and Landscapes	Nursery	http://plantsandlandscapes.com.au/
Yarra Ranges Shire Council	Government	http://fe.yarraranges.vic.gov.au/Residents/Trees_Vegetation/Yarra_Ranges_Plant_Directory
Greening Australia Capital Region	Not for profit	http://www.greeningaustralia.org.au/
World wide wattle - WA Herbarium	Herbarium	http://worldwidewattle.com/
Victorian Government Department of Sustainability and Environment	Government	http://www.environment.gov.au/
Woolshed Thurgoona Landcare Group	Not for profit	http://wtlandcare.org/
ERA Nurseries	Nursery	http://www.eranurseries.com.au/
VICFLORA - Royal Botanic gardens Victoria	Government	https://vicflora.rbg.vic.gov.au/
Treelogic	Private Consulting Business	https://treelogic.com.au/
Australian Native Plants Society (Australia)	Not for profit	http://anpsa.org.au/index.html
Speciality Trees	Nursery	https://www.specialitytrees.com.au/
Gardening with Angus	Nursery	https://www.gardeningwithangus.com.au/
The Tutu guru	Nursery	https://www.thetutuguru.com.au/
Plants for a Future (PFAF)	Not for profit	https://pfaf.org/User/Default.aspx
Riot Act - Canberra	News	https://the-riotact.com/
Missouri Botanical Garden	Not for profit	http://www.missouribotanicalgarden.org/
Southern Woods	Nursery	https://www.southernwoods.co.nz/
Davis Landscape Architects	Private business	https://davisla.wordpress.com/
Wikipedia	Not for profit	https://en.wikipedia.org/wiki/Main_Page
Oaks of the World	Not for profit	http://oaks.of.the.world.free.fr/index.htm
Arboapp - Identification guide for the wild trees of the Iberian Peninsula and Balearic Islands - Royal Botanic Gardens Spain	Botanic garden	http://www.arbolapp.es/en/
European Atlas of Forest Tree Species - Joint Research Centre - European Commission's science and knowledge service	Government	http://forest.jrc.ec.europa.eu/european-atlas-of-forest-tree-species/
University of Florida - Environmental Horticulture Department	University	https://hort.ifas.ufl.edu/
Plants Database - Natural Resources Conservation Service - United States Department of Agriculture.	Government	https://plants.sc.egov.usda.gov/java/
European Forest Genetic Resources Programme (EUROFGEN)	International cooperation	http://www.euforgen.org/
IUCN Red List of Threatened Species	United Nations	http://www.iucnredlist.org/
Small Tree Farm: Deciduous Tree Nursery Balingup	Nursery	http://www.smalltreefarm.com.au/index.html
Useful Temperate Plants Database	Not for profit	http://temperate.theferns.info/
Woodland Trust	Not for profit	https://www.woodlandtrust.org.uk/
Oklahoma Forestry Services - A Division of the Oklahoma Department of Agriculture, Food, and Forestry	Government	http://www.forestry.ok.gov/
Go Botany -New England Wild Flower Society	Not for profit	https://gobotany.newenglandwild.org/
Wageningen University - Forest Ecology and Forest Management Group	University	https://www.wur.nl/en/Research-Results/Chair-groups/Environmental-Sciences/Forest-Ecology-and-Forest-Management-Group.htm
Virginia Tech - College of Natural Resource and Environment - Dendrology	University	http://dendro.cnre.vt.edu/dendrology/index.html

Source	Type	Website
University of Connecticut - COLLEGE OF AGRICULTURE, HEALTH AND NATURAL RESOURCES - Plant Database	University	http://www.hort.uconn.edu/plants/index.php
Milan Havlis - Specialty garden centre	Nursery	https://www.havlis.cz/index_en.php?
U.S. National Plant Germplasm System - Germplasm Resources Information Network(GRIN) - United States Department of Agriculture - Agriculture Research Services	Government	https://www.ars-grin.gov/
Stephen Ryan Horticulture	Nursery	http://stephenryan.com.au/
Ministry of Agriculture Greece	Government	http://www.moa.gov.cy/moa/agriculture.nsf/index_gr/index_gr?opendocument
Winter Hill Tree Farm	Nursery	http://www.winterhill.com.au/
The National Gardening Association	Not for profit	https://garden.org/plants/
Invasive Plant Atlas of New England - The University of Georgia - Centre for Invasive Species and Ecosystem Health	University	http://www.eddmaps.org/ipane/
Gardens Online - Plant finder	Nursery database	https://www.gardensonline.com.au/GardenShed/PlantFinder/
Van Den Berk Nurseries	Nursery	https://www.vdberk.com/
Backyard gardener	Nursery	https://www.backyardgardener.com/
Blerick tree farm	Nursery	http://www.onlinetrees.com.au/
Plants of the World Online -Kew Science - Royal Botanic gardens	Botanic Garden	http://powo.science.kew.org/
International Organisation of Palaeobotany	International cooperation	https://www.palaeobotany.org/home/
Encyclopaedia or Life	Not for profit	http://www.eol.org/
Select Tree - Urban Forest Ecosystems Institute - California Polytechnic State University	University	https://selectree.calpoly.edu/
Canadian Science Publishing	Publisher	http://www.nrcresearchpress.com/
Deepdale Trees	Nursery	http://www.deepdale-trees.co.uk/
Royal Horticultural Society	Not for profit	https://www.rhs.org.uk/plants
Flora of North America	Not for profit	http://www.efloras.org/flora_page.aspx?flora_id=1
Calflora - Consortium of California Herbaria	Not for profit	http://www.calflora.org/
Calscape - California Native Plant Society	Not for profit	https://calscape.org/
Northern Research Station - Forest Service - United States Department of Agriculture	Government	https://www.nrs.fs.fed.us/
Mt William Advanced tree Nursery	Nursery	https://www.advancedtrees.com.au/
Victorian Resources Online - Agriculture Victoria - Department of Economic Development, Jobs, Transport and Resources	Government	http://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/vrohome
Tree Co	Nursery	http://treeco-treeco.blogspot.com/
Sun trees	Nursery	http://suntrees.co.za/
Plantmark Wholesale Nursery	Nursery	https://www.plantmark.com.au/
Arbor Day Foundation	Not for profit	https://www.arborday.org/
Waverly Council	Government	http://www.waverley.nsw.gov.au/
University of Florida - Institute of Food and Agricultural Sciences - Electronic Data Information Source	University	http://edis.ifas.ufl.edu/
United States Department of Agriculture - Animal and Plant Health Inspection Service	Government	https://www.aphis.usda.gov/aphis/home/
Preliminary study on the germination of Toona sinensis (A. Juss.) roem. seed from eleven Chinese provenances - Forest Ecology and Management, Vol 10, Iss. 3, 1985	Journal Article	https://www.sciencedirect.com/science/article/pii/0378112785901197
Learn2grow	Not for profit	http://www.learn2grow.com/
Inner West Council (Marrickville)	Government	https://www.innerwest.nsw.gov.au/
University of Valencia	University	https://www.uv.es/jgpausas/index.htm
Chileflora	Not for profit	http://www.chileflora.com/index.html
Gardening Australia	News	http://www.abc.net.au/gardening/
Department of Agriculture and Fisheries - Queensland Government	Government	https://www.daf.qld.gov.au/
Agroforestry - Rowan Reid	Private business	http://www.agroforestry.net.au/main.asp?_=Home
Ellenby Tree farm	Nursery	http://ellenbytreefarm.com/
Blerick tree farm	Nursery	https://bareroottrees.com.au/
Findmepalnts	Nursery	http://www.findmeplants.co.uk/
Resistant Elms	Nursery	http://www.resistantelms.co.uk/
Barcham - the tree Specialists	Nursery	https://www.barcham.co.uk/
Vermont Urban and Community Forestry	Not for profit	https://vtcommunityforestry.org/
NC State Extension - NC State University	University	https://plants.ces.ncsu.edu/plants/plant-list
Gardenia	Nursery	https://www.gardenia.net/
Monrovia	Nursery	https://www.monrovia.com/
Botanic Gardens Conservation International	Not for profit	https://www.bgci.org/
Hansen's Northwest Native Plant Database	Not for profit	http://www.nwplants.com/index.html
Floridata	Not for profit	https://floridata.com/home/
Centre for invasive Species and Ecosystem Health	Not for profit	https://www.invasive.org/
Plantlust	Nursery	https://plantlust.com/

Source	Type	Website
An assessment of the drought tolerance of Fraxinus genotypes for urban landscape plantings, *Urban Forestry & Urban Greening* 5(1):17-27 · June 2006	Nursery	https://www.researchgate.net/publication/229411110_An_assessment_of_the_drought_tolerance_of_Fraxinus_genotypes_for_urban_landscape_plantings
Alpine Treemovals	Nursery	http://www.treemovals.com.au/index.php
Home Design Directory	Nursery	https://www.homedesigndirectory.com.au/
University of British Columbia	University	https://blogs.ubc.ca/landscapeplants2/
Plant facts - Ohio State University	University	https://plantfacts.osu.edu/
Dave's Garden	Nursery	https://davesgarden.com/
Online Plant Guide	Nursery	http://www.onlineplantguide.com/Index.aspx
Oxford plants 400 - University of Oxford herbaria	University	https://herbaria.plants.ox.ac.uk/bol/plants400
Handbook of Herbs and Spices (Second edition), Volume 1, Woodhead Publishing Series in Food Science, Technology and Nutrition, 2012, Pages 73-85	Journal Article	https://www.sciencedirect.com/science/article/pii/B9780857090393500050
Arnold Arboretum of Harvard University	University	http://arnoldia.arboretum.harvard.edu/
Whitehorse Council, Victoria	Government	http://www.whitehorse.vic.gov.au/
World Agroforestry Centre	Not for profit	http://www.worldagroforestry.org/
Pacific Horticulture Society	Not for profit	https://www.pacifichorticulture.org/
Botanic Group	Nursery	https://www.botanicgroup.com/en/
City of Stirling, Western Australia	Government	https://www.stirling.wa.gov.au/
Arbotnet - Quality Advanced Trees	Nursery	http://arbornet.com.au/
Institute of Food and Agricultural Sciences - University of Florida	University	http://lyra.ifas.ufl.edu/NorthernTrees/
Global Invasive Species Database - IUCN -International Union for Conservation of Nature	International cooperation	http://issg.org/database/welcome/
Bunnings	Nursery	https://www.bunnings.com.au/
Prestige plants	Nursery	http://www.prestigeplants.com.au/
Agriculture (formerly RIRDC)	Government	https://www.agrifutures.com.au/
Oregon State University - Department of Horticulture - Landscape plants	University	https://landscapeplants.oregonstate.edu/
Aggie horticulture	University	https://aggie-horticulture.tamu.edu/
The Garden of Eaden	Nursery	https://gardenofeaden.blogspot.com/
Pippin trees	Nursery	https://www.pippintrees.co.uk/
Urban Forest Nursery	Nursery	http://www.urbanforestnursery.com/index.html
The Morton Arboretum	Arboretum	http://www.mortonarb.org/
Woody Plants Database - Cornell University	University	http://woodyplants.cals.cornell.edu/home
American Conifer Society	Not for profit	http://conifersociety.org/
Discover Life	Not for profit	https://www.discoverlife.org/
Global Biodiversity Information Facility - Free and open access to biodiversity data	Not for profit	https://www.gbif.org/