Hort Innovation

Final Report

Which plant where, when and why database for growing urban green space

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Which plant where, when and why database for growing urban green space (GC15002)

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PUBLIC SUMMARY

The Which plant where, when and why database for growing urban green space project (Which Plant Where), funded through the Hort Innovation Green Cities fund, was developed to facilitate sustainable green cities by unlocking opportunities to develop resilient urban green spaces and drive sustainable market growth for the horticultural industry. Specifically, the overall aim of the five-year program of work was to:

- Identify plant species that will be suitable in Australian cities under climate change
- Increase the diversity of species planted in Australian urban landscapes
- Drive market growth for the horticultural industry
- Facilitate sustainable and resilient green spaces
- Develop tools and resources to be used by a wide range of stakeholders.

Which Plant Where's stakeholders included growers and the nursery trade industry, plant specifiers and practitioners in government and industry, urban forest managers, arborists, landscape architects and urban planners. The research team took a user-centered approach, working closely with stakeholders to co-design research and develop tools and resources that would be useful and relevant.

Our initial engagement program uncovered common barriers and problems faced by growers and practitioners beyond species selection. These findings provided the foundation for the design of the research program to enable development of an evidence-based integrated tool to support urban greening, including planning, stakeholder engagement, climate-ready species selection, site condition and preparation, and ongoing maintenance and monitoring regimes.

The research program consisted of four inter-related research modules: **Module One – Species attributes and climatic tolerance.** In this module we collated a database of over 2500 species, hybrids and cultivars including traits on plant form, environmental tolerances, co-benefits (shade, carbon, biodiversity) and risks. Bioclimatic modelling was undertaken for all species for which sufficient occurrence data were available, resulting in the development of national-level maps of climatic suitability for each species; **Module Two – Successes and failures.** In this module 12 Living Labs were developed in collaboration with local councils in Queensland, New South Wales and Victoria, information on urban forest inventories and on success and failures of urban plantings was compiled, biodiversity and cooling benefits of urban plants were assessed, and an Urban Forest demonstration site was developed; **Module Three – Heat and drought tolerant species**. In this module a protocol for assessing heat and drought tolerance of species was developed. A total of 113 plant species were grown in common glasshouse environments and subjected to an experimental heatwave and/or drought; **Module Four – Species selection online tool**. Module Four developed an online climate-ready plant selector tool, which is the first of its kind globally. Research outcomes from Modules 1-3 have been integrated and translated into the online plant selector tool as well as best practice guidelines and articles that are easy to understand by multiple stakeholders. The tool provides unique evidence-based support for urban greening initiatives and is supported with a fully developed Business Plan.

Throughout the five-year program we engaged with over 1,000 people and have systematically built a brand for Which Plant Where across Australia. Our engagement strategy included National Roadshows, national industry events, substantial media coverage, state industry events, research outcome webinars, as well as workshops and focus groups for the development of the online plant selector tool. The Which Plant Where tool will be launched in April 2022 and is designed to be self-sustaining to enable regular updates and expansion. Recommended next steps for the tool include a national promotional campaign and exploration of extensions to enable integration with other urban planning and nursery industry tools, input of data from practitioners to improve the modelling outputs and recommendations, and a discussion forum to enable communication and sharing of knowledge within the urban greening industry. The vision is for the Which Plant Where tool to become the 'go to' website for the urban greening industry.

KEYWORDS
Species selection; climate change; heat tolerance; drought tolerance; urban greening

INTRODUCTION
Australia is a highly urbanized nation, with more than 80% of the population living in urban areas and projected to increase in the future (United Nations 2019). These urban areas face significant challenges, including urban heat and extreme climate events, poor water and soil management, air pollution, and loss of biodiversity. On top of the urban heat island effect, climate-change predictions are that Australian cities will face hotter temperatures, more-intense and more-frequent storms and bushfires, and potentially new pests and pathogens (Lewis et al. 2017; Di Virgilio et al. 2019). Urban green areas can provide nature-based solutions to these challenges and deliver a broad range of benefits including climate change mitigation through carbon uptake and storage, adaptation through urban cooling and better stormwater management (Livesley et al. 2016), air pollution mitigation, enhanced biodiversity, and even improved human health and well-being (Lin et al. 2019).

To reap the benefits from urban green areas, we need to ensure that our urban plant species are resilient to climate change and that our urban green spaces are planned, planted and managed so that they can thrive and deliver the desired benefits. There are many components to building this resilience, ranging from the individual plant level to the precinct- to city-scale. The overall objectives of the Which Plant Where project were to: (1) reduce vulnerability and risks to urban and peri-urban plantings from harsh environmental conditions; (2) improve the resilience and tolerance of green spaces to extreme heat and drought conditions; (3) increase the diversity of species used in urban green spaces; and (4) support biodiversity values of urban plantings.

The Which Plant Where project was developed initially out of earlier urban greening initiatives (e.g. SA Botanic Garden's plant selector tool, City of Melbourne Urban Forest Strategy) and the 202020Vision Plan. In the five years since Which Plant Where started, there has been a substantial increase in the development of urban forest strategies at local and state government levels, focused on building resilience through urban greening initiatives, however the evidence-base remains insufficient. Which Plant Where was designed to build the evidence-base for successful and resilient urban greening and to deliver outcomes that directly addressed the key objectives of Hort Innovation's Green Cities Strategic Investment Plan: (1) To highlight how urban greening can mitigate the effects of climate change; (2) To facilitate urban greening through the development of usable tools and resources; (3) To promote market expansion by identifying appropriate species and design principles for increased urban greening; (4) To work iteratively with stakeholders to identify and overcome barriers to the implementation of research findings.

METHDOLOGY
The Which Plant Where project had a comprehensive five-year research program consisting of four integrated modules.

Module One – Species attributes and climatic tolerance (Macquarie University)

In this module we collated a database of over 2500 species, hybrids and cultivars. The species list was determined based on input and feedback from stakeholders including growers and the nursery industry and included the most commonly available horticultural species as well as less common 'new opportunity' species. All species names were checked for taxonomic accuracy. Based on feedback from the Which Plant Where Advisory council, the list is approximately 65% native Australian species and 35% exotic species, and is dominated by woody growth forms (trees, shrubs, 65%) but includes grasses, herbs and climbers. Information was collated where available for all species on: plant form (height, canopy size, deciduous/evergreen, phenology, flower colour), site preferences (soils, urban space type, use),

environmental tolerance (shade, drought, frost, coastal), co-benefits (shade, carbon, biodiversity) and risks (invasive, allergen). Images of each species illustrating form, flowers and fruits were sourced.

Climatic suitability assessment of all species for which sufficient occurrence data were available (1373 species) was undertaken to identify areas suitable for the species to grow under both current and future climates (2030, 2050, 2070). We used two approaches to estimate the climatic suitability for each species, at postcode-level. For most species, we developed Species Distribution Models (which we refer to as our SDM method). Where this was not possible, we used a simpler approach which we refer to as our niche method. The technical description of both approaches is provided in Appendix 1. All analyses were undertaken in the R (v 3.4.4) software environment (R Development Core Team, 2017).

Module Two – Successes and failures, and co-benefits (Western Sydney University)

This module had several components. Information on successes and failures of urban street tree plantings was sought from local government areas around Australia, as well as information on councils' approaches to urban forest management (e.g. data collected as part of street tree inventories).

Measurements of street tree performance along a climatic gradient within Sydney were undertaken to assess species' plasticity in response to growing conditions. Five species were assessed, and trait variation was measured.

A series of 12 Urban Living Labs (ULL) were set up in collaboration with local councils in Queensland, New South Wales and Victoria. Each ULL had plantings of different structural complexity (mixture of trees and shrubs) which will be used to assess biodiversity responses to structural diversity of urban plantings. An Urban Forest demonstration site was set up on the Western Sydney University Hawkesbury campus in 2021, with support from the NSW Greening the City Program, to assess performance of 48 species (16 exotic and 32 natives). This will assess performance of tree species from a variety of climate zones, providing additional information to the climatic suitability modelling (Module 1) and glasshouse trials (Module 3). These trees will be monitored (water use, leaf transpiration and cooling benefit) every three months for the duration of their three-year establishment period (2021-2024).

Module Three – Heat and drought tolerant species (Western Sydney University and Macquarie University)

In this module 113 plant species were subjected to controlled drought and heatwave conditions in the glasshouses at Western Sydney University and Macquarie University. Plant performance was assessed using the standardized screening protocol we developed to quantify 3 core traits: (1) chlorophyll fluorescence (Fv/Fm) as a stress indicator, (2) the critical temperature (Tcrit), which indicates the point when photosynthesis of leaves is irreparably damaged by heat, and (3) leaf osmotic potential (πo), which is closely related to wilting point during drought. We also visually determined foliage damage of all study plants before and after the heat wave. In addition, plant traits such as leaf area, specific leaf area and leaf dry matter content were measured for each species. Details of how we measured drought and heat tolerance are provided in Appendix 2. We also compiled information on drought tolerance from the horticultural literature and reputable online sources, and undertook a multivariate analysis to compare drought tolerance of species as identified by the horticultural industry with leaf-level ecophysiological traits (leaf mass per area, leaf thickness, unit leaf area, leaf dry matter content and leaf water potential at turgor loss point) (details in Tabassum et al. 2021).

Module Four – Species selection online tool (Macquarie University)

Module 4 brought together the key outcomes from Modules 1-3 into an accessible online tool (the Which Plant Where tool) for urban greening professionals. A software development company was contracted to develop the online tool (Circul8). Stakeholder engagement resulted in design input for the tool for functionality and user experience. The foundation for the climate-ready plant selector

component of the tool was the database and bioclimatic modelling undertaken in Module 1. Resources, including best practice guidelines (Appendix 3), were developed that enhance the tool and provide essential information for urban greening professionals, covering Climate Change, Resilient Urban Landscapes, Planning, Monitoring and Maintenance, and Community Engagement. A robust Business Plan for the Which Plant Where tool was developed in consultation with Hort Innovation to facilitate the long-term sustainability of the tool, enabling updates and enhancements into the future.

Which Plant Where team members in the glasshouse and labs

RESULTS AND DISCUSSION

The Which Plant Where project produced an enormous amount of data across the five years of the project. For ease of presentation for this Final Report, the results are summarized into Engagement and Research by Module.

ENGAGEMENT

The WPW team ran a series of initial workshops (year 1) around Australia (Brisbane, Adelaide, Melbourne, Perth and Sydney) to promote the project and engage with stakeholders to understand their needs. These workshops attracted over 111 people from 86 organisations, bringing together a diverse group of stakeholders including major nursery growers, representatives of local government areas, arborists and landscape planners and designers and researchers. The outcome was published as a 'What we heard' document that highlights our key findings (Appendix 4).

The Which Plant Where website was developed to showcase the project, provide an engaging journey along the project roadmap with regular updates, insights from the researchers, and overviews of the

research projects underway. The website (www.whichplantwhere.com.au) has provided a stable and regularly-updated portal for the materials and outcomes of the research, hosting media interviews, research updates, team profiles and other content that has supported the direction of the project and its outreach efforts through live and social media channels. The website has had over 21000 unique user visits, with most visits coming directly to the site or through search engines, and 25% from other referrals such as media links on ABC, The Conversation, Sydney Morning Herald, and other coverage. Most social traffic came from Facebook (68%), followed by LinkedIn (12%) and Twitter (12%). Feedback from stakeholders and researchers indicated that the website and its related social channels, media coverage, team profiles and other content positively supported the outcomes and impact emerging from the five-year project.

Conference presentations, workshops and webinars were held throughout the life of the project, designed to share the research findings and key recommendations. These were highly successful in promoting the Which Plant Where project and its findings, resulting in high recognition in the industry and extensive media coverage. The list of presentations is shown in Appendix 5 and details of media coverage are provided in Appendix 6.

RESEARCH

Module One – Species attributes and climate tolerance

The final Which Plant Where database comprises 1840 species, 508 cultivars, 33 subspecies, 27 hybrids, 9 hybrid cultivars and 91 genus cultivars. These represent 150 plant families and 662 genera, with 62% native to Australia and 38% exotic. We obtained 100% data coverage for the following variables for all species: common name, height, width, deciduousness, shade tolerance, flower colour, flower period, urban context and uses, and over 90% coverage for soil texture and frost tolerance. This represents the most comprehensive and up-to-date database produced for ornamental plants sold in Australia.

For the first phase of modelling we assessed the distribution of climatically suitable habitat under baseline, 2030 and 2070 conditions for 176 tree species native to Australia, that are commonly planted across Australia's Significant Urban Areas (SUAs). We found that by 2070, climatically suitable habitat in these SUAs is predicted to decline for 73% of species. This highlights the importance of identifying climate-ready species for urban plantings (Burley et al. 2019).

For the climate suitability modelling that is the foundation of the online tool, we obtained sufficient occurrence data to undertake climatic suitability modelling for 1373 native and exotic species. Our climate suitability models were developed for three time periods (2030, 2050, and 2070) and spanned 2670 postcodes from across the country. We evaluated the performance of the model for each species using best practice approaches and expert opinion, retaining only those models with sufficient predictive power. The final outputs included maps classifying postcodes as being ‘UNSUITABLE’ or ‘MARGINAL’ or ‘SUITABLE’ for the species.

For species with insufficient data to develop climate suitability models, we used a variant of the above, whereby we compared the temperature and precipitation range each species is known to tolerate to the conditions predicted to occur at each postcode. Again, this enabled us to classify postcodes as ‘UNSUITABLE’ or ‘MARGINAL’ or ‘SUITABLE’ for the species.

Combined, the two approaches amounted to more than 4,000,000 estimates of the climate suitability of species across Australia, which are accessible through the Which Plant Where plant-selector tool.

Module Two – Successes and failures, and co-benefits

Air temperature and multiple surface temperatures were measured for a total of 514 trees, covering 13 species, across five LGAs. Assessment of cooling benefits showed that average air temperature was 1.1°C (± 0.67°C) lower under canopies, with a maximum cooling benefit of 3.7°C (± 0.3°C). Additional research undertaken by Macquarie University in collaboration with South Australia’s AdaptWest showed that urban vegetation can reduce land surface temperature on extreme heat days by up to 6°C, with

tree canopy providing a stronger cooling effect than grassy areas (Ossola et al. 2021).

140 LGAs were contacted to obtain data on successes and failures of tree plantings, and on availability of tree inventories. It was found that very few councils maintain good records of successes and failures of their plantings in parks and streetscapes, and few maintain high quality inventories of their tree assets. However, information was able to be obtained from 43 Significant Urban Areas (SUAs) and 218 LGAs, providing a list of 5138 species planted and growing (= "successes") across Australia, as well as a list from 11 SUAs and 14 LGAs of 280 species listed as 'unsuitable'. Large tree inventories with greater than 50,000 individual trees are held by 80 LGAs in Australia. An online survey on the status and availability of tree inventory data found that over half of councils that responded had tree inventory data, recording branch failure and tree mortality. However, there are major limitations with the data, including inconsistent recording of information. Consequently, we have developed the following resources for the Which Plant Where online tool that will help urban greening professionals to better monitor and manage their urban tree assets: '*Climate-ready street tree trials: a best practice guide'* and '*How to measure your urban forest*' (see Appendix 3).

Results from the climatic gradient sites in Sydney showed that the five tree species were quite variable ('plastic') in their traits in relation to climate, suggesting that this adaptive capacity can be harnessed for species selection to improve urban forest resilience to climate change (published in Esperon-Rodriguez et al. 2020).

A total of 12 WPW Living labs were established in four states, covering a temperature and precipitation gradient across Australia, from the warmer and wetter site in the Sunshine Coast, to the cooler and drier site in Canberra. Assessment of survival and performance of these Living Labs has highlighted the importance of stock quality, planting technique, planting context, soil volume and site conditions. These findings provided important guidance for the development of the '*How to measure your urban forest*' and '*How to successfully establish your new trees'* best practice guidelines and resources associated with the WPW tool (Appendix 3).

Module Three – Heat and drought tolerant species

A total of 113 species were assessed for heat and drought tolerance under glasshouse experimental conditions. Heat tolerance was surveyed on the basis of visual damage to plants during heatwaves as well as damage to the leaves measured by chlorophyll fluorescence. Drought tolerance was surveyed and ranked using the turgor loss point of leaves, equating to the plant wilting point, using commercial instrumentation. Multivariate analysis of the 113 species based on trait and turgor loss point data resulted in three distinct groups on the basis of their traits, which correspond to three fundamental drought strategies: 'dehydration avoiders', 'dehydration tolerators' and an 'intermediate' mixture of the two strategies. Dehydration tolerators and avoiders are considered 'drought tolerant' by the horticultural industry. We suggest that distinguishing between dehydration avoidance and dehydration tolerance may help to enhance horticultural guidelines by better informing which species are suitable for particular biophysical and landscape contexts (Tabassum et al. 2021). These data provided a quantitative basis for ranking species for tolerance of adverse climatic conditions, and provided the scientific basis of data presented in the Which Plant Where online tool.

A common garden experiment on four species on the Hawkesbury campus of WSU assessed heat tolerance during heatwaves and showed that leaf damage under heatwave conditions was lower for the two exotic species compared to the two native species (Esperon-Rodriguez et al. 2021). A large field assessment of >5500 urban street trees in the Penrith LGA in western Sydney after an extreme heatwave found that >10% of all trees showed some foliage damage, with exotic deciduous species (such as *Quercus palustris* and *Magnolia grandiflora*) the most vulnerable. Replacement costs were calculated as $500,000-$800,000 (Tabassum et al. 2021).

Module Four – Species selection online tool

The Which Plant Where online plant selection tool (whichplantwhere.com.au) has been developed and is due for launching in April 2022. It enables users to search by location (postcode/suburb) or by species, and has a set of 11 filters to enable users to specify growth form, urban space type, plant size, shade tolerance, origin, soil type, etc. Species are listed in order of climatic suitability, with those most suitable for the named location listed first. Suggestions for similar species are included, in order to diversify users' species selection. The tool also enables users to create, save and export a species palette, where planting diversity, total canopy cover, biodiversity value, shade value and carbon value are calculated. The tool is supported with a wide range of resources, covering climate change, resilient urban landscapes, planning, monitoring and maintenance, and community engagement. There is no other plant selector tool with accompanying resources available anywhere in the world that has this high level of functionality enabling selection of climate-ready species, and facilitating successful planning, development, and implementation of urban green space.

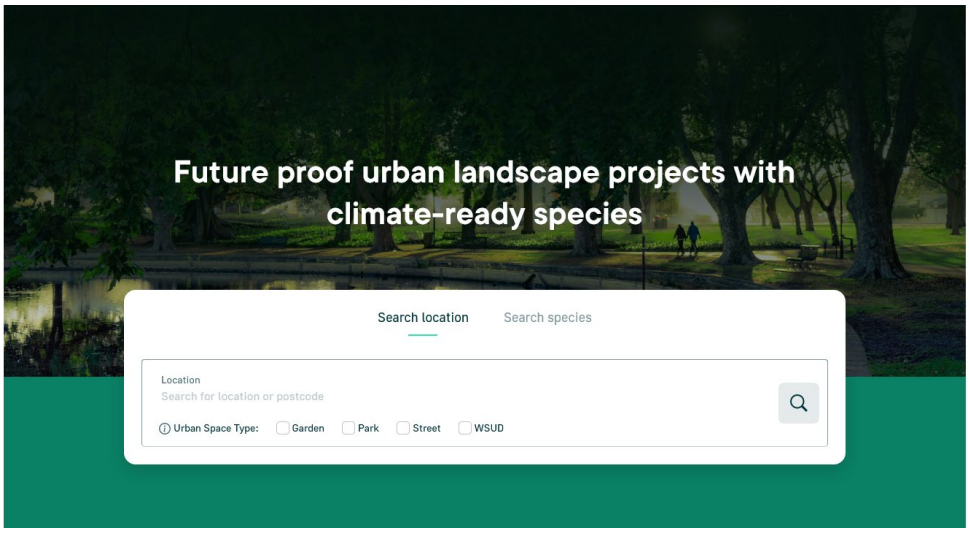
Which Plant Where team members visit a production nursery

A Which Plant Where living lab

OUTPUTS

The key output of this project is the Which Plant Where tool (www.whichplantwhere.com.au), which is a subscription-based website that allows users to search for plants (over 2500 species and varieties) that will be suitable in any given location in Australia based on three future climate scenarios – 2030, 2050 and 2070. Subscribers will be able to access the latest scientific climate modelling and mapping as well as functionality such as a co-benefits calculator, canopy cover estimator and palette creator.

A list of all other outputs (factsheets, best practice guidelines, technical reports) and extension activities (presentations, webinars, etc.) are provided in Appendix 7 and Appendix 5.



Landing page of the Which Plant Where online tool

OUTCOMES

Table 1. Summary of outcomes from Which Plant Where

Outcome	Alignment to fund outcome, strategy and KPI	Description	Evidence
Identification of a diverse range of plant species that will be suitable in Australian cities under future climates. This will result in more diverse and resilient urban green spaces	Promote market expansion by identifying appropriate species and design principles for increased urban greening	Stakeholder engagement throughout the project identified the barriers to successful urban greening and knowledge-gap on climate suitability of species. Presentations have shown the project research outcomes and tool to a variety of sectors of the urban greening industry	Attendance at webinars and other stakeholder events
Developed resources on climate change and resilience of urban green spaces	Highlight how urban greening can mitigate the effects of climate change	Best Practice Guidelines and a wide range of articles on climate change, urban greening benefits & green space resilience are available to the public on the Which Plant Where online tool	The Which Plant Where tool will be launched in April 2022 – data on usage will become available
Developed tools and resources that will facilitate more sustainable and resilient urban green spaces	Facilitate urban greening through the development of usable tools and resources	Best Practice Guidelines and a wide range of articles on climate change, urban greening benefits & green space resilience are available to the public on the Which Plant Where online tool	The Which Plant Where tool will be launched in April 2022 – data on usage will become available

Development of a subscription-based online plant selector tool that will support the urban greening and horticultural industry and be self-sustaining	Facilitate urban greening through the development of usable tools and resources Promote market expansion by identifying appropriate species and design principles for increased urban greening	The Which Plant Where tool has been developed, enabling selection of climate-suitable plant species for all Australian urban regions. The tool has publicly available resources for users as well as subscription-only contents that will provide a revenue stream to ensure it is regularly updated and self-sustaining	The Which Plant Where tool will be launched in April 2022 – data on usage will become available

MONITORING AND EVALUATION

All milestones of the Which Plant Where project were delivered, as detailed in Table 2.

Table 2. Key Milestones of the Which Plant Where project

Key Milestones	Project performance	Continuous improvement opportunities
MS102 Stakeholder incubation meeting in three states	Due to the popularity of the workshop the project ran five workshops (rather than three) in Brisbane, Adelaide, Melbourne, Perth and Sydney. These workshops attracted over 111 people from 86 diverse organisations.	All attendees were entered into the WPW CMS and communication with them via regular WPW program updates prioritized. Follow up on the 'What we Heard' document embedded in the research program, and to be delivered in the WPW plant selector tool.
MS103 Project fact sheet	A project factsheet was produced and made available at stakeholder workshops	To maintain a continuously updated platform for engagement, the Which Plant Where website was developed
MS103 Update of species list	Input from key stakeholders resulted in a final species list of approximately 2500 species, cultivars and hybrids.	Suggestions of additional species sought from stakeholders throughout project
MS103 Webinar for growers	From discussion with Cox Inall, this was replaced with an article on WPW in the July newsletter	Maintained relationship with Cox Inall throughout life of the project to promote WPW.
MS104 Develop standardized screening protocol	Experimental protocols for assessing heat and drought tolerance of plant species were developed and implemented in the glasshouse trials. The screening results (113 species tested) were translated to drought and heat tolerance classes. Webinar presentations were delivered in 2021	The innovative experimental protocol was published (Marchin et al. 2020) and the approach for ranking species based on drought tolerance was published (Tabassum et al. 2021).
MS104, 105, 109 Biomonitoring	12 WPW Living Labs were developed in collaboration with	Results from the WPW Living Labs guided the development of the Best

plantings at 10 sites	local councils, with findings used to identify factors that impact planting and establishment success. Biomonitoring sites were established along a climate gradient within Sydney. Findings were published in Esperon-Rodriguez et al. 2020 The WPW Urban Forest was established at the Hawkesbury campus of WSU.	Practice Guidelines built into the WPW plant selector tool e.g. 'Climate-ready street tree trials' (whichplantwhere.com.au/resources) The WPW Urban Forest will provide data on species performance and the role of climate change, and is a project that will provide data over coming years beyond the life of the WPW project. Additional funding was obtained through a Greening the City grant from NSW Government.
MS106 Growth trials in 10 nurseries	Visits were conducted to 10 different nurseries to conduct "Science in the Nurseries". Standard measurements of plant performance were undertaken.	Understanding of nursery conditions and growers' needs was incorporated into the WPW plant selector tool resources
MS107, 108 Co-benefit assessments at 5 sites	Measurement of cooling benefits: air temperature and multiple surface temperatures (shade vs sun) were measured under the canopy for a total of 514 trees, covering 63 species, across five LGAs in Sydney.	Factsheet on cooling benefits produced. Learnings were incorporated into the WPW plant selector tool resources
MS107 Completion of species distribution maps	Climate suitability modelling output and maps completed and incorporated into WPW plant selector tool	Analysis of horticultural species vulnerability to climate change published (Burley et al 2019), with follow-up media arising from article in The Conversation
MS108 Presentation of success/failure data	Webinar titled 'Embracing our successes and failures to create better urban green spaces' was delivered to ~100 people. National online webinar presented titled "How to monitor your urban forest for the future", reaching ~40 participants	Learnings were incorporated into WPW plant selector tool resources e.g. 'Best practice guidelines for measuring your urban forests'
MS109 Environmental suitability of species and new opportunity species	Findings presented in webinar titled 'Opportunity species' (2021), attended by 50 people, and in a factsheet. Scientific paper on heat and drought stress published (Marchin et al. 2022)	Learnings were incorporated into WPW plant selector tool resources
MS109 Scientific paper on plant response to water availability	Paper titled "Utilising a trait-based approach to classify drought strategies of common horticultural species" published (Tabassum et al. 2021)	Data on species' drought tolerance was incorporated into the WPW plant selector tool
MS109, 110 Development of commercialization plan for WPW online tool	Stakeholder meetings for online tool development held (but restricted due to COVID-19). Full business plan presented to Hort Innovation. Software developers contracted by MQ, beta version developed and tested.	Feedback from stakeholder meetings and user interviews and experience were incorporated into the tool development

MS111 Launch of online tool	The WPW online tool is due for launch in early April 2022. It is based on the database of 2500 species, cultivars and hybrids, climatic suitability analysis and mapping, and includes ~6000 plant images. The tool is supported by a large range of resources, including best practice guidelines for urban greening from planning to monitoring and maintenance. A soft launch is planned for April 2022, followed throughout the year with a series of roadshows, webinars and industry events to promote the tool.	Feedback on the current version will be incorporated to enable continual improvement of the tool. See 'Recommendations' for further development of the tool. Macquarie University is supporting the launch and promotion of the tool in 2022, including salary support for a WPW Business Development Manager, with the aim to develop the tool into a self-sustaining entity that can be regularly updated and expanded, delivering the 'go to' website for urban greening professionals.

RECOMMENDATIONS

The Which Plant Where plant selector tool was designed to be self-sustaining in the long-term, to enable regular updates of the climate suitability modeling and species data, increase in species coverage, and integration with other urban green space and nursery industry programs. It aims to be the 'go to' resource for urban greening professionals and provide a collaborative hub for the exchange of information. To achieve this, the following is recommended:

- Development of a program to promote the Which Plant Where tool widely across the industry (growers, nurseries, arborists, urban planners, landscape architects, practitioners), including information sessions, media coverage, roadshow, etc.
- Exploration of opportunities to integrate the Which Plant Where tool with other urban greening and nursery programs e.g. the Gardening Responsibly PlantSure scheme, BASIX (Building Sustainably Index)
- Development of Continuing Professional Development (CPD) credit offerings for members of professional organisations that attend a webinar or WPW training session and development of micro-credential units associated with postgraduate courses in Sustainability, Forestry and Urban Planning
- Expansion of capacity of the tool to enable collection of data on successes and failures so that practitioner experiences are captured and shared, and to expand the input for species' bioclimatic models to improve climate suitability outputs
- Improved quantification of co-benefits at the species-level e.g. urban cooling, water use, carbon uptake and storage, air pollution trapping and retention, biodiversity support
- Research to understand diversity within the horticultural industry, from within-species to precinct-, city-and national-scales, in order to build resilience of Australia's urban forests
- Research to better understand threats to urban greening and how to manage them e.g. conflicts with infrastructure, climate-related pests and pathogens
- Research on the use of soil amendments to increase plant resilience to heat and drought stress
- Investigation of opportunities for smart urban forestry to improve management and reduce costs of managing urban green spaces

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Plant species database

The plant species data base contains over 2500 plant species and descriptions for elements such as their physical parameters (i.e. height and width), preferred site conditions, tolerances (drought/frost/ salt) and urban application (i.e. Street tree/ Park Street, WSUD).

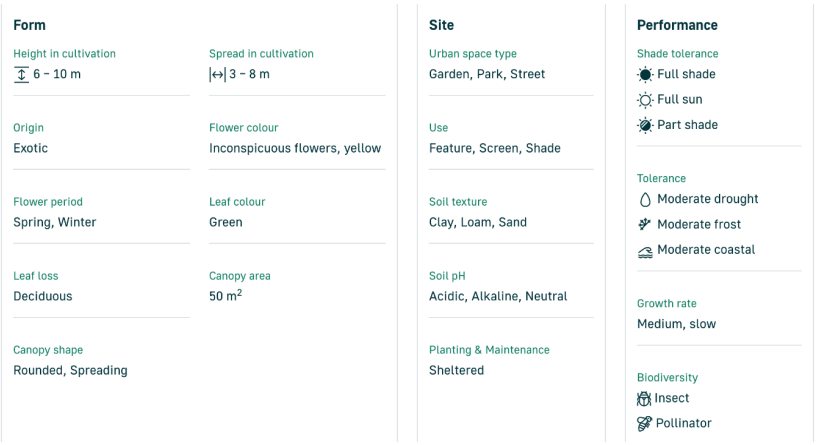

Figure 1. Example of a species profile page based on the trait database

Climate suitability modelling and mapping

Climate suitability maps for each species in the tool have been produced to identify areas suitable for the species to grow in, under both current and future climates. These maps were created using modelling techniques which utilised species occurrence records and climate data to extrapolate the most suitable growing regions for species under a variety of climate scenarios.

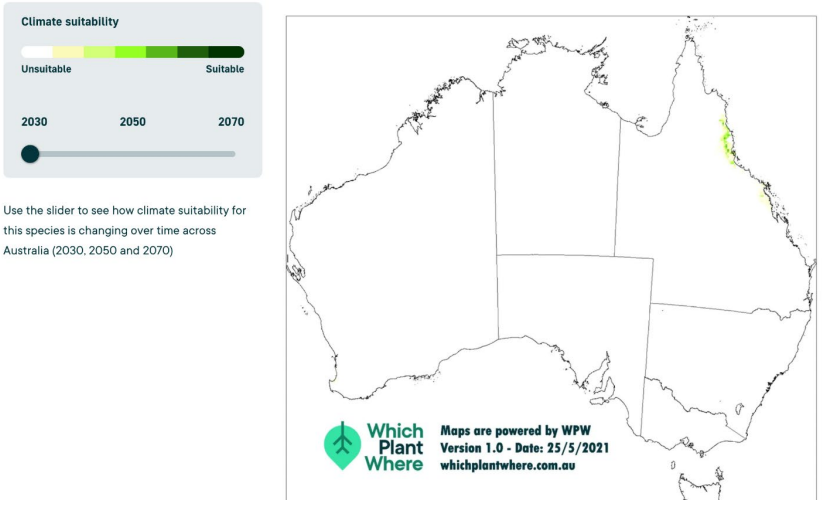

Figure 2. Example climate suitability map

Local occurrence and global occurrence of plants is also provided on the website but is not the IP of WPW – this information is derived from Australia's Living Atlas (ala.org.au) and/or the Global Biodiversity Information Portal (gbif.org).

Glasshouse experiments and living lab research

A range of data presented within the web tool was derived from research undertaken in the glasshouse experiments (Module 3) and living lab trials (Module 2). This data is owned by Which Plant Where (Macquarie University and Western Sydney University) and forms part of the IP contained within the plant selector tool.

Image database

Images used on the website are not owned by Which Plant Where, they are used with permission and credited to the owner of each image. They do however form part of the IP contained within the plant selector tool.

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Figure 3. Example of images and credits from the Which Plant Where tool

COMMERCIALISATION

As part of the commercialisation of the project, Which Plant Where will be launching a subscription-based business model for use of the online plant selector tool. The subscription cost is $1200 per year. There will be a free component to the website which will allow any visitor to the site to view information such as: plant species data (height, width etc.), images, soil characteristics and environmental tolerances. A range of written resources are also available and include blog style written reports on topics relevant to the sector. This information is a valuable contribution to the urban greening industry and is freely available.

Subscribers to the online tool will be given access to the climate suitability modeling component of the website and will be able to search for plants that will be suitable in any given location in Australia based on three future climate scenarios. Subscribers will also be able to access the scientific climate mapping as well as functionality such as a canopy estimator, co-benefits calculator and palette creator.

The subscription model has been selected to ensure the program is self-sustaining into the future. For the online tool to continue to be relevant in the market it needs to stay up to date, provide revised climate data and offer future enhancements and functionality. This was a strong theme identified during the stakeholder engagement workshops. To achieve this, a reliable income stream is required to fund additional research, web development and program staff.

ACKNOWLEDGEMENTS

The Which Plant Where project acknowledges the key role played by Leigh Staas, Project Manager 2016-2021, and the efforts of all the research teams at Macquarie University and Western Sydney University. The project also acknowledges the invaluable advice provided by the project's Advisory Committee and the input and feedback provided by stakeholders and participants through workshops, industry events, seminars and webinars, including 202020Vision (now Greener Spaces Better Places) and Cox Inall. Thanks also to Byron de Kock at Hort Innovation for his support of the Which Plant Where project.

APPENDICES

Appendix 1: How we calculated climate suitability in Which Plant Where

https://whichplantwhere.com.au/resources

Appendix 2: How we measured drought and heat tolerance in Which Plant Where

https://whichplantwhere.com.au/resources

Appendix 3: Best practice guidelines:
3.1 Climate-ready street tree trials: a best practice guide;
3.2 How to successfully establish your new trees;
3.3 How to measure your urban forest;
3.4 What tree growers need from you

https://whichplantwhere.com.au/resources

Appendix 4: Which Plant Where 'What we heard' document

Published 2017

Appendix 5: Which Plant Where presentations delivered throughout the project

Appendix 6: Media coverage of the Which Plant Where project

Appendix 7: Summary of outputs from the Which Plant Where project

Appendix 8: Fact sheet: Which Plant Where project

Published June 2017

Appendix 9: Nursery Papers (August 2017)

Nursery and Garden Industry Australia

Appendix 10: Screening protocol for seeking climate-hardy horticultural species and varieties in the WPW project

Published December 2017

Appendix 11: Which Plant Where Living Lab

Published June 2018

Appendix 12: Plants of the Future

Gardening Australia (March 2019)

Appendix 13: Fact sheet: Cooling benefits of urban trees

Published December 2019

Appendix 14: Fact sheet: Environmental suitability of horticultural plants

Published June 2020

Appendix 15: How we calculated planting co-benefits in Which Plant Where

https://whichplantwhere.com.au/resources

Appendix 16: How we calculated canopy cover in Which Plant Where

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Appendix 17: How we calculated planting diversity in Which Plant Where

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Appendix 18: What is a weed and how are they identified in Which Plant Where

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Appendix 1:

How we calculated climate suitability in Which Plant Where

https://whichplantwhere.com.au/resources

Which Plant Where

How we estimated the climatic suitability for each species, at postcode-level

By Linda J Beaumont and Farzin Shabani, 28th September 2021

For Which Plant Where, we used two approaches to estimate the climatic suitability for each species, at postcode-level. For most species, we developed Species Distribution Models (which we refer to as our **SDM** method). Where this was not possible, we used a simpler approach which we refer to as our **niche** method. Below, we provide a technical description of both. All analyses were undertaken in the R (v 3.4.4) software environment (R Development Core Team, 2017).

WHAT ARE SDMS AND HOW DO THEY WORK?

Species distribution models (**SDMs**) are numerical tools commonly used to identify the distribution of environmental and climate conditions suitable for a species, under current, past or future epochs. SDMs form the foundation of the Which Plant Where plant selection tool, providing an estimate of the climatic suitability for a given species at a given postcode.

Briefly, SDMs require two types of data: a list of the coordinates of locations where a species is known to occur, and gridded environmental variables (i.e., maps) that span those locations (Figure 1). The environmental variables are assumed to be factors that influence the distribution of the species. The values of the environmental variables are extracted for every occurrence location. A numerical model is then developed describing the relationship between where the species occurs and the environment across that region. The model is then projected back onto the environmental layers to create suitability maps, both for current and future climate conditions.

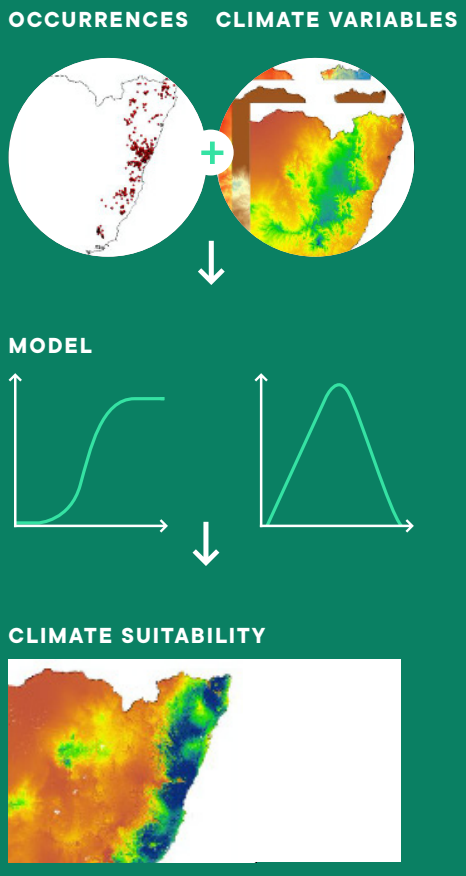

FIGURE 1 Diagrammatic representation of how a Species Distribution Model (SDM) works. Occurrence data is combined with climate variables under current climate conditions. A statistical model is developed describing the relationship between occurrences and variables, leading to the development of map showing suitability of a region for a species.

OCCURRENCE RECORDS

The Global Biodiversity Information Facility (GBIF) and Atlas of Living Australia (ALA) databases contain details of plant specimens in herbaria, and observations from scientific and citizen science projects, from across the world. For WPW, we downloaded global records for each of our target species. We then 'cleaned' records to extract only those containing coordinates (latitude and longitude), and to remove any that were duplicated or had errors. An SDM was then created (or 'fitted') for any species with at least 30 occurrence records from unique locations. Please note that cultivars and varieties are assimilated to the respective species, where available, due to the lack of robust occurrence records for these taxa.

CLIMATE DATA

For Which Plant Where, we used only climate variables within our SDMs, as other environmental factors, such as soil, can be readily altered in urban environments. Climate data were obtained from CHELSA (v 1.2, Karger et al., 2017), which contains high-resolution climatologies spanning the earth's land surface. These are gridded data where the resolution of each grid cell is 30 arc seconds (approximately 1 km x 1 km at the equator). We used CHELSA's bioclimatic data, which includes 19 climatic variables commonly used in SDMs. The 'baseline' epoch consists of climate data averaged over the period 1979–2015. CHELSA's future climatologies represent two 20-year epochs centred on 2050 and 2070. These data were originally derived from multiple Global Climate Models (GCM), downscaled through CHELSA to 30 arc seconds. Given that there is variation in the output of GCMs, it is very important for impact studies, such as Which Plant Where, to utilize data from multiple GCMs with low interdependence in order to improve accuracy of model predictions. To this end, we used 10 GCMs identified as per Sanderson et al., 2015 (ACCESS10, CESM1BGC, CESM1CAM5, CMCCCM, FIOESM, GISSE2H, INMCM4, IPSLCM5AMR, MIROC5, and MPIESMMR). Simulations from these models were based on Representative Concentration Pathway (RCP 8.5), which projects that greenhouse gas emissions will continue to steadily rise throughout the 21st century (Meinshausen et al., 2011). CHELSA does not provide data for 2030, hence we generated these for each GCM through a linear interpolation based on the baseline and 2050 data. As such, the three future epochs we used are centred in 2030, 2050 and 2070.

SPECIES DISTRIBUTION MODEL

There are multiple SDM algorithms available for use in impact studies. Of these, a machine-learning approach, MaxEnt (Phillips et al., 2006; Elith et al., 2011), has become widely used, largely because it has been shown to be very effective compared to many other models (Elith et al., 2006). MaxEnt is reliant on a geographical background defined by the user for the purpose of comparing the background's climate to the climate from where the species is present. For Which Plant Where, this background was species-specific, based on randomly selected grid cells within 500 km of occurrence records. Within the MaxEnt algorithm, we used linear, product and quadratic features to fit models.

For each species, we fitted a model using a species-specific subset of the 19 bioclimatic variables. We then evaluated the performance of the model using the area under the receiver operating characteristic curve (AUC) and the true-skill statistic (TSS). While these two measures are useful for assessing model performance, it is still possible for a model to record high AUC or TSS, yet for the resulting map of climate suitability to be biologically unrealistic. As such, in addition to relying on AUC or TSS scores, three trained members of our team also independently validated maps of the projected climate suitability across Australia for each species, as well as projected suitability across the native range of exotic species (i.e. those not native to Australia). Each team member classified each model as either acceptable or unacceptable. New improved models were then fitted for any species with poor AUC/TSS or which had a model deemed as unacceptable. There remained, however, a number of species (principally exotic to Australia) for which acceptable models could not be fitted. For these, we used the *niche approach* to identify climatic suitability of each postcode.

Acceptable models were then projected onto each of the future climatologies. When undertaking SDMs—particularly when projecting onto future climates—it is important to remove areas identified as climatically suitable solely due to extrapolation into non-analogue climates. Non-analogue climates are those that are outside of what is described by the occurrences and background data used to fit the model. These are conditions for which it is unclear whether the species can tolerate, and excluding these regions is good modelling practice. We identified areas of extrapolation by generating Multivariate Environmental Similarity Surfaces (MESS) and clipping these areas out of the maps of climate suitability.

Final model output for each species consisted of 10 maps (representing the 10 climatologies) for each of the 2030, 2050 and 2070 epochs, with values ranging from 0 (least climatically suitable) to 1 (most climatically suitable). These maps were stacked to produce a new comprehensive map with grid cells representing the median value across the 10 climatologies (referred to below as the Spp_{median} map).

CLIMATE SUITABILITY AT THE POSTCODE LEVEL FOR SPECIES WITH SDMS

Within Which Plant Where, we report the climatic suitability of each postcode for each species. In doing so, we use postcodes described in the Postal Areas ASGS Ed 2016 Digital Boundaries, from the Australian Statistical Geography Standard (ASGS). It should be pointed out that some postcodes can cover large climatic gradients. This presents difficulties when summarizing climatic suitability, as there may be some areas with very low suitability whereas other areas have higher suitability. Yet the postcode-level summary will simply report 'unsuitable, 'marginal' or 'suitable'.

For a given species and time period, we overlaid the Spp_{median} map with that of the postcodes. We then calculated median suitability across all of the grid cells within the postcode. Next, we went back to the original MaxEnt model for the species, and extracted the 5th and 10th *percentile values of cumulative logistic thresholds*. MaxEnt produces a number of similar thresholds that are commonly used to place continuous suitability values (which range from 0–1) into categories (usually just *suitable* and *unsuitable*). The 5th and 10th *percentile values of cumulative logistic thresholds* are the suitability values that fall at the 5th and 10th percentile when values for every grid cell are placed into a cumulative histogram. Any postcode with a suitability value equal to or less than the 5th percentile was deemed *unsuitable*. A postcode with a value above the 5th and equal to or less than the 10th percentile was deemed *marginal*, and postcodes above the 10th percentile were deemed *suitable*.

NICHE METHOD

For some species, there were insufficient data to create SDMs (i.e., fewer than 30 occurrence records) or SDMs were of poor quality (typically exotic species with few to no occurrences in Australia in GBIF/ALA). For these species, we used a variant of the above SDM whereby we obtained CHELSA data for average maximum temperature of the warmest month (MTWM) and average precipitation of the driest month (PDM), for each occurrence. We then calculated the minimum, maximum, 5% and 95% values across these species' occurrences for the baseline period.

Simultaneously, we calculated the median value of both variables across each postcode for the baseline and three future epochs (2030, 2050, 2070), for each of the GCMs. We then created a series of rules to classify each postcode as *unsuitable, marginal,* or *suitable* for each species and time period, based upon the median values of the postcode for the two climate variables relative to those of the species' niche.

UNSUITABLE: The median value of either MTWM or PDM for the postcode is smaller (or larger) than the minimum or maximum values of the species' niche. This indicates that much-to-all of the postcode is likely to be too cool/dry (hot/wet) for the species.

MARGINAL: The median values of the postcode lie within the 0–5% or 95–100% values of the species' niche for either variable.

SUITABLE: The median values of the postcode lie within the 5–95% values of the species niche, for both variables.

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Appendix 2:

How we measured drought and heat tolerance in Which Plant Where

https://whichplantwhere.com.au/resources

How we measured drought and heat tolerance in Which Plant Where

By Samiya Tabassum, Michelle Leishman & David Ellsworth, 28th September 2021

In the Which Plant Where plant selection tool, there are a number of species and cultivars for which we have additional information on drought and heat tolerance. This information is based on rigorous testing conducted in *state-of-the-art* climate-controlled glasshouses, both at Macquarie University and Western Sydney University.

WHAT WE DID

A total of 113 perennial plant species and cultivars, including both native and exotic to Australia and across five different growth forms (trees, shrubs, climbers, herbs, graminoids), were selected for the experiments. These species were a mixture of species commonly available in the Australian horticultural market, as well as uncommon species less readily available commercially and infrequently planted in urban areas.

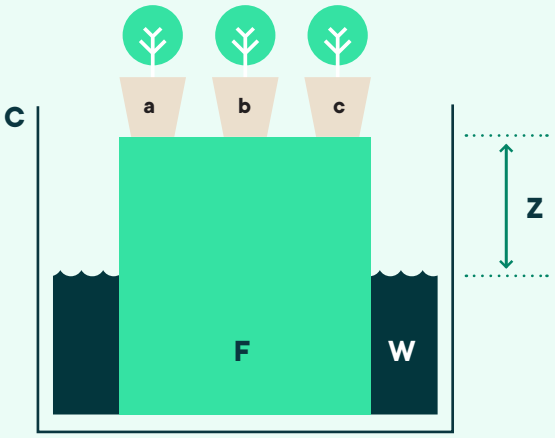
All plants used in the glasshouse experiments were obtained from commercial Australian nurseries as either tubestock, 140 mm or 200 mm pot size. The original soil/media from around the roots of each plant was carefully removed and plants were re-potted into 6 L pots (or 9 L pots for larger individuals) containing native potting mix (<30% sand/coir, >70% screened composted pine bark; Australian Growing Solutions, Tyabb, VIC, Australia), 38 g of controlled release native plant fertiliser (Scotts Australia Osmocote Slow Release, Bella Vista, NSW, Australia), and a 1.25 g systemic insecticide and fertiliser tablet (Yates Confidor, Padstow, NSW, Australia). All plants were well watered using drip irrigation, and grown for 6-7 weeks in the glasshouses to allow for acclimation and the formation of new leaves. This reduced the chance that cultural practises in source nurseries would cause unexplained variation in the results. Plants were maintained at an average temperature of 27 °C, with a day time range of 21 – 34 °C. These temperatures were chosen to mimic warm, summer urban conditions that could occur in the major centres of Australia, but were not excessive or stressful temperatures for plant species in this study.

After approximately two months of acclimation, plants were assigned to one of four treatments; control (plants remained well-watered and grown at average summer temperatures), drought (plants were subjected to a controlled drought while growing at average summer temperatures), heat wave (plants were subjected to elevated temperatures while being well watered) and a combination of drought and heatwave (plants were subjected to drought conditions and elevated temperatures).

DROUGHT TREATMENT

For the plants in the drought treatment, a gradual drought was imposed to slowly dry the soil, simulating natural drought events in the field. Pots were placed in large plastic containers on top of a block of commercial florist foam (Fig. 1). The large container was then filled with water to just below the top of the florist foam. The gradual drought was then imposed by slowly decreasing the level of the water (z in Fig. 1) over a period of a month. Water was drawn down from the large container until volumetric water content (VWC) of the soil in pots reached ~10%, after which period this VWC level was maintained for three weeks to ensure that plants experienced an adequate level of stress from the drought.

FIGURE 1 Diagram of the drought imposition method, where *C* plastic container, *F* floral foam, *W* water, a,b,c pots with nylon mesh at the bottom and filled with potting mix, and z water table depth. Figure from Marchin *et al.* 2020.



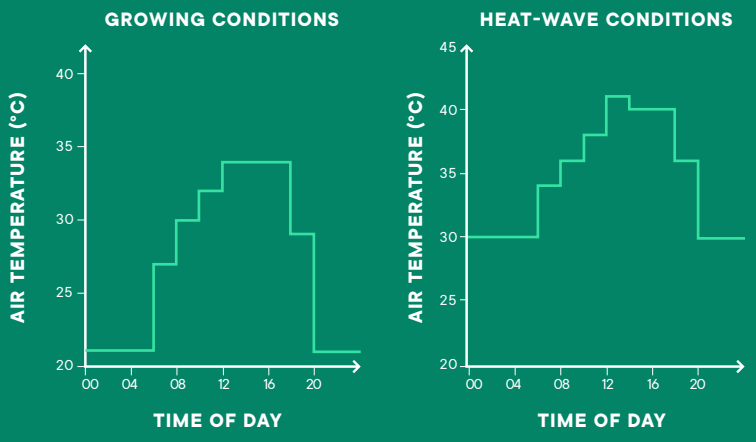


FIGURE 2 Daily temperature profile of the growing conditions (left panel) and heat wave conditions (right panel) for the glasshouse experiments.

HEATWAVE TREATMENT

Plants in the heatwave treatment were exposed to a six day heatwave after the drought period. During the heatwave, the average temperature of the glasshouse was 35 °C (8 °C warmer on average than the control temperature, Fig. 2), reaching a maximum of 41 °C. Air humidity was kept high during the heatwave regime to avoid the confounding effects of vapour pressure deficit and heat on plants.

WHAT WE MEASURED

In order to formulate drought and heat tolerance information, the Which Plant Where team measured a range of traits on the experimental plants.

DROUGHT TOLERANCE TRAITS

LEAF AREA: Plants with smaller sized leaves have been shown to have lower vulnerability to drought due to more efficient water transport. In general, large leaved species are most common in wet environments whereas small leaved species are most common in hot, arid environments. To measure leaf area, we collected 1-5 mature leaves from each plant and scanned them using a flatbed scanner. We then used image analysis software to calculate individual leaf area.

LEAF MASS PER AREA (LMA): Leaves with high LMA are often associated with stiffer cell walls that are more physically resilient to water loss during dry periods. LMA is calculated as the dry mass of a leaf divided by its area. To measure LMA, we collected 1-5 mature leaves for each plant and scanned them using a flatbed scanner. We used image analysis software to calculate individual leaf area. These leaves were then oven dried at 70 °C for at least 72 hours before they were weighed to obtain dry mass, using a digital scale.

LEAF THICKNESS: Thick leaves are often associated with stiffer cell walls that are more physically resilient to water loss during dry periods. Leaf thickness was measured on 1-5 mature leaves for each plant. Thickness measurements were taken at three points along each leaf using digital callipers, near the tip, middle and bottom, being careful to avoid any major veins, and averaged for each leaf.

LEAF DRY MATTER CONTENT (LDMC): LDMC is the ratio between leaf dry mass divided by its fresh mass. Leaves with high LDMC are often associated with stiffer cell walls that are more physically resilient to water loss during dry periods. LDMC was measured on 1-5 mature leaves per plant.

TURGOR LOSS POINT (TLP): Leaf water potential at turgor loss point (TLP, or wilting point) is the water potential value at which a leaf loses turgor, and is strongly related to drought tolerance (Fig. 3). Species with more negative TLP have higher leaf-level drought tolerance. Up until now, TLP measurements have typically been conducted using pressure-volume curves, which often take several hours to several days to complete for a single species. However, for the Which Plant Where experiments, we used a relatively new technique which measures osmotic potential (a trait strongly related to TLP) and gives results within 30 minutes. Briefly, 1-5 leaves were removed from each plant and hydrated in water for three hours. A 40 mm diameter disk was then cut out of each leaf and frozen in liquid nitrogen for two minutes. Leaf discs were then allowed to thaw at room temperature in a humidified bag for 10 minutes before being punctured 50-70 times with fine tipped forceps. Osmotic potential values were then measured on the leaf discs using a dewpoint hydrometer, with these values being converted to TLP values, using established equations (Bartlett et al., 2012a).

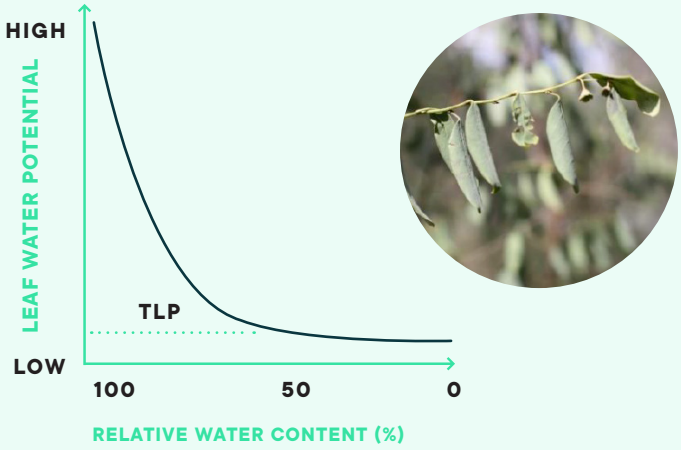


FIGURE 3 Graph showing the point where TLP is reached and (insert) leaves that have reached their TLP. Graph modified from Bartlett *et al.,* 2012b.

HEAT TOLERANCE TRAITS VISUAL ASSESSMENT OF DAMAGE: One of the most noticeable signs that a plant is suffering from heat stress is the visible browning and desiccation of leaves as cells begin to die. We assessed the effect of the heatwave on plants by visually estimating the percentage of leaf desiccation at the whole plant level after the final day of the heatwave.

DARK-ADAPTED CHLOROPHYLL FLUORESCENCE (Fv/Fm): Fv/Fm represents a measure of how 'healthy' green leaves of a plant are. During photosynthesis, light enters the chloroplasts in leaves, but not all of the light energy can be used by the plant. This unused light energy is released back as red light and this is known as fluorescence. This fluorescence can be measured using a Pulse Amplitude Modulated (PAM) fluorometer, which emits a high intensity beam of light onto a leaf surface and measures the amount of light reflected back (fluorescence). In order to take this measurement, plants were first dark adapted for 30 minutes to allow all of the reaction centres in the chloroplasts to be ready to receive light. 'Fo' is the background level of fluorescence when the plant has been kept in the dark (Fig. 4). A strong pulse of light is then fired onto the leaf by the PAM machine, saturating all the reaction centres. 'Fm', or maximal fluorescence, is then measured when all the reaction centres have been saturated and the excess light energy is emitted. Fv/Fm is then calculated as variable fluorescence (which is Fm – Fo) divided by Fm (Fig. 4). High values of Fv/Fm indicate that the plant is healthy with healthy photosynthetic machinery. Low values of Fv/Fm, however, indicate that a plant may be stressed as the photosynthetic machinery may be damaged.

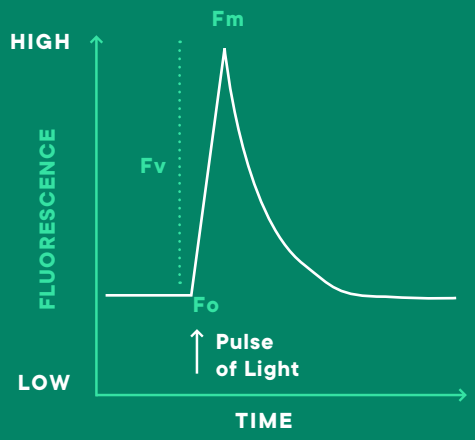


FIGURE 4 Diagram showing a typical fluorescence curve and the relationship between Fm, Fo and Fv.

LEAF CRITICAL TEMPERATURE (Tcrit): Tcrit marks the temperature where the photosynthetic machinery of a leaf starts to fail and cell death occurs. We measured Tcrit on five individuals of all species by placing a mature leaf on top of a thermoelectric heater and raising the leaf temperatures from 30 °C to 60 °C at the rate of 1 °C per minute. Fluorescence of the leaf was measured with the PAM machine, with the exact temperature at which leaves began to die marked by the sharp increase in fluorescence as photosynthetic machinery is damaged (Fig. 5). Tcrit can be used to rank species based on thermal tolerance, with plants from warmer regions found to have higher Tcrit values.

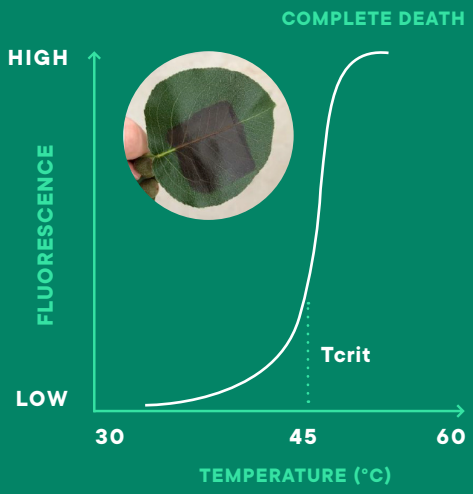


FIGURE 5 Graph showing the point where Tcrit is reached and (insert) the aftermath of Tcrit testing on a leaf. Graph modified from Knight & Ackerly 2002.

DROUGHT TOLERANCE CLASSES

Drought tolerance classes were calculated by conducting a principle components analysis (PCA) on the drought tolerance traits (LMA, leaf area, leaf thickness, LDMC, TLP). A principle components analysis essentially takes data that would ordinarily be multi-dimensional (in this case our data would be in five dimensions because we measured five traits) and represents this in two dimensions, preserving as much information as possible. In this analysis, each species is represented by a single point, with points clustering together in space if species have similar traits. PCA analysis provides a powerful and impartial means to understand how species cluster together based on similarities and dissimilarities between their traits.

After conducting a PCA analysis on our data, we found that our study species clustered into three distinct groups, meaning the species in each cluster were more similar to each other than species in other clusters, based on their drought tolerance traits (Fig. 6). Further analysis revealed which traits each cluster of species shared with each other. As it turns out, our computer-generated clustering matched perfectly with our knowledge of drought strategies from the scientific literature. This allowed us to define three distinct groups of 'drought strategy' based on particular combinations of traits:

DROUGHT TOLERATOR: Species in this cluster had high LMA and LDMC, thick leaves and low (more negative) TLP, characteristic of a drought tolerator strategy.

DROUGHT AVOIDER: Species in this cluster had low LMA and LDMC and high (less negative) TLP, characteristic of a drought avoider strategy. Many of these species lost leaves during drought and can be considered drought deciduous.

INTERMEDIATE (TOLERATOR/ AVOIDER): Species in this cluster had a combination of tolerator and avoider traits, namely, high LDMC, large, thin leaves, low LMA and high (less negative) TLP.

For more information on the difference between drought tolerators and drought avoiders, please refer to the blog post titled 'drought tolerators vs drought avoiders'.

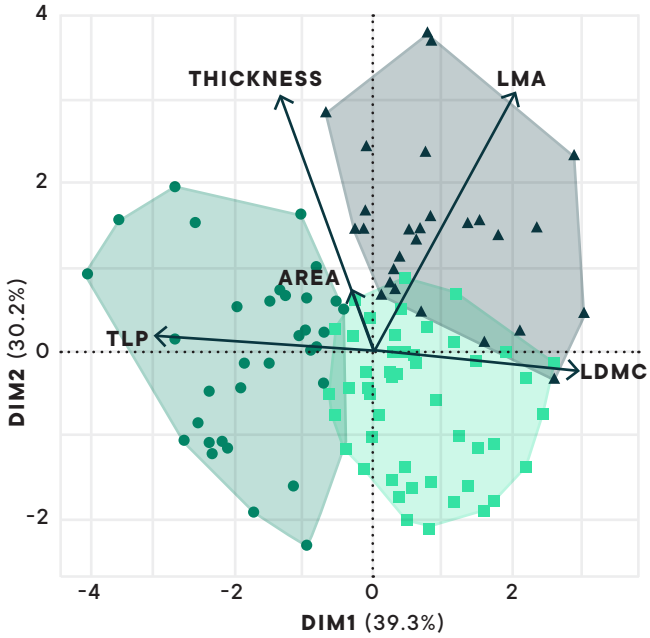


FIGURE 6 Visual representation of the PCA results for the drought tolerance traits, with species colour coded into their respective groups. The directions of the arrows represent increasing values for that trait. Modified from Tabassum *el at.*, 2021.

HEAT TOLERANCE RANKINGS

Heat tolerance rankings were calculated by weighting the heat tolerance traits (60% visual damage, 20% Tcrit, 20% Fv/Fm), which were then used to classify species into four categories (sensitive, intermediate, intermediate/tolerant, tolerant). These categories were determined based on the distribution of values for the heat tolerance traits.

CAVEATS

It is important to note that the heat rankings on the Which Plant Where selection tool are based on relative comparisons between the study species. As more and more species are tested experimentally in the glasshouse, it is likely that these rankings may change as we gather more data. Furthermore, plants were only subjected to one heatwave treatment, with additional testing underway to assess species' responses to multiple heatwaves. Nonetheless, rankings like these may be used to validate existing knowledge about tolerances of horticultural species and also identify up and coming opportunity species that may be well suited to urban planting.

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Appendix 3:

Best practice guidelines

3.1 Climate-ready street tree trials: a best practice guide

https://whichplantwhere.com.au/resources

Which Plant Where

Climate ready street tree trials

A best practice guide

FEBRUARY 2022

ACKNOWLEDGEMENT OF COUNTRY

We acknowledge Aboriginal and Torres Strait Islander peoples as the First People and traditional custodians of the land and waters of this place. We express our gratitude in sharing this land, our sorrow for the personal, spiritual and cultural costs of that sharing, and our hope that we may walk forward together in harmony and the spirit of healing.

This "How-to" guide for climate ready street tree trials was developed in collaboration between the Which Plant Where (Macquarie University, Western Sydney University) and TREENET.

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Image and Graphic credit – Gwilym Griffiths, Good Canopy Company.

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Which Plant Where

WESTERN SYDNEY UNIVERSITY

MACQUARIE University SYDNEY-AUSTRALIA

hort frontiers Strategic partnership initiative | GREEN CITIES FUND

treenet

CONTENTS

01. INTRODUCTION

02. STRATEGIC PLANNING

03. DESIGN & IMPLEMENTATION

04. DATA SHARING & ADDITIONAL RESOURCES

01.
INTRODUCTION

WHICH PLANT WHERE

Street trees are on the front line of urban forest service delivery, supporting neighbourhood character, human health, waterway health, biodiversity, tourism and business vitality. In order to deliver these benefits, street trees must be well suited to the local conditions. Currently, urban ecosystems are experiencing unprecedented levels of warming and shifts in rainfall patterns due to climate change, which means tree species selections that have succeeded in the past may fail to do so in the future. Therefore, it is vital that climate ready tree species for urban greening are identified to ensure the resilience of urban environments to climate change. This can be achieved through street tree trials.

This "how to" guide provides an easy-to-follow, step-by-step plan to designing and implementing a scientifically rigorous trial of street tree species in an urban context. The aim of this guide is to assist tree nurseries and local councils to consistently apply basic scientific principles so that:

- tree species' suitability to changing local conditions can be tested, measured and evaluated
- a participative, co-designed approach to street tree trials can be implemented
- results can be compared with similar trials in other locations
- councils, tree growers and other agencies can collaborate to extend trials into new areas
- knowledge can be shared to increase species diversity and enhance urban forest resilience

INTRODUCTION

There are six easy steps that need to be followed to ensure that your street tree trial is a success. Collectively, these steps will ensure that trials are scientifically robust and results can be easily shared.

1. Defining your outcome
2. Selecting a species
3. Identifying your trial site
4. Designing and planting your trial
5. Monitoring
6. Data sharing

02.
STRATEGIC PLANNING

Why

Start with the Why!
Why are you undertaking street tree trials and what questions do you want answered?

STEP 1: DEFINING YOUR OUTCOME

1.1 – The Why
Start with the Why! This will help you define the outcome. What is your vision? What are your goals? What questions do you want to answer? Basically, what do you want to achieve? For example, you may be planning your future urban forest and want to identify new species that will be climate-ready. The questions are endless. However, to gain valuable insights and answer your questions correctly, you need robust data. This will take good planning and preparation.

1.2 – Time commitment
Before beginning a trial, it is important to realise that it will require a significant time commitment over multiple years (minimum 2 years). It is better to decide prior to the start of the trial whether such a time commitment is feasible. Although a trial is a significant time commitment, the long term benefits of having a thriving urban forest in your urban area will make the effort more than worthwhile.

STEP 2: SELECTING YOUR TRIAL SPECIES

2.1 – Find species that are climate ready (Know the future climate for your area)
Many parts of Australia are experiencing unprecedented levels of warming and shifts in rainfall patterns. Changes in these two climate factors can have a profound effect on the survival and success of urban tree species. Therefore, it is important to select a trial tree species that may not only withstand current climatic conditions but future projected conditions as well. The 'Which Plant Where' online plant selector tool is an easy way to determine how particular species will survive under predicted future climate of your area. The tool uses climate projections that can then be used to identify locations with current conditions that match those forecast for your area. Species occurring naturally or succeeding as street trees in those locations may be good candidates for trialling in your area.

2.2 – Be aware of your space constraints
Space in urban areas is often constrained by impervious surfaces (e.g. roads, footpaths) and other infrastructure (e.g. water, sewerage, electrical). Therefore, it is important to select a trial species that will fit within these space constraints. Further, it is important to remember that in urban areas small trees are spaced at 5 to 7 m intervals, medium trees at 7 to 10 m and large trees at 10 to 15 m. In the long-term, this foresight will minimise maintenance costs (e.g. pruning, removal and replacement) and infrastructure damage (e.g. lifting and cracking of footpaths and roads).

2.3 - Know your species diversity
Plant species diversity is important for improving the structure and function of urban forests. It increases resilience to stresses such as drought, pests and disease, provides food and shelter for fauna, and has aesthetic benefits. For these reasons, an emphasis should be placed on increasing the species diversity within your urban area when selecting a trial species. This is as easy as surveying the species that are already present in the locality and then selecting trial species from an unrepresented or under-represented genus or family.

2.4 - Engage and expand your networks
There is often a wealth of useful information already out there that can help you decide what species to trial. It is worth chatting with neighbouring councils, local bush regeneration groups, growers, botanic gardens and community gardening groups to find out what species have already been trialled in the area and the lessons learnt from those trials. This could save a lot of time and money in the long term, or at the very least, provide some helpful information.

STEP 3. IDENTIFYING YOUR TRIAL SITE

3.1 - Select a site that is like for like
When selecting a site for your trial, it must be representative of the site in which you intend to eventually plant the species being trialled. Soil type, water availability and space constraints are all important factors to consider when selecting a site. For example, sites in urban areas are normally characterised by a turfed verge bound by impervious surfaces. Therefore, it may inappropriate to trial a prospective species for a site like this in an open field.

3.2 - Select a mix of high profile sites and low profile sites
Trial species are exactly that, a trial. This implies that there is a degree of uncertainty regarding whether trees will survive and thrive. Some trial trees won't survive, so it is best that trial sites are dispersed across both low trafficked areas (e.g. cul-de-sacs) and more frequented sites. Before beginning a trial, it is worth undertaking some community engagement to explain the rationale of the trial to the community; creating a sign or placing a tag on the tree highlighting that is it part of a trial can also help inform the community and provide an opportunity to take stewardship of the tree and potentially monitoring the tree.

3.3 - Be flexible
Space in urban areas is often at a premium, so it is important to strike a balance between finding the perfect site and being flexible to ensure your trial can get off the ground. In many cases, being opportunistic may be the only realistic way to secure a site.

03.
DESIGN & IMPLEMENTATION

How

Replication, replication, replication is the key to good science and robust data.

STEP 4. DESIGNING AND IMPLEMENTING YOUR TRIAL

4.1 – Treatments
Treatments are things you may wish to test, such as watering regime, mulching and fertiliser addition. For example, if you want to trial a species that has been identified as drought tolerant, you may want to test plant performance under different watering conditions (or treatments). To test this, get 20 plants of the same species. 10 will be the "control" plants and receive business as usual. 10 will be the "treatment" plants and receive (for example) 50% less water.

4.2 – Controls
If you have a treatment (e.g. watering regime, soil amendments) as part of your trial's experimental design, it is important that you also have "control" plants to determine the effect of the treatment/s. Control plants should ideally have the same number of replicates as the treated plants.

4.3 - Replication, replication, replication
Replication is the key to good science. Why? Plants from the same species still display some degree of genetic variation. This means that even when you grow plants under the same environmental conditions, they will still vary in their growth and appearance. To capture this variability, multiple individual plants per treatment are required. This is called replication, with each plant within a treatment called a replicate. Ideally, the more replicates you can plant, the better, as it will increase the amount of variability you capture and hence your certainty of the result. However, given the space constraints within the urban areas, it is often not feasible to plant out large-scale experiments, so the minimum number of replicates (i.e. individual plants of each species per treatment) you should aim for in your trial is 8-10.

4.4 - Randomisation
To minimise the effects of environmental factors on your trial, individuals from different treatments must be randomly allocated positions within your trial site. For example, if 20 trees in total are being planted, 10 with a watering well (treatment) and 10 with a soil berm (control), don't plant the 10 with wells next to each other, followed by the 10 with berms. This is because environmental factors such as soil type may vary across the trial site. An easy way to randomise your plants is to have, for example, a red marble that represents the watering well and a blue marble that represents the berm. Put the marbles in your pocket and then take one out one marble to determine which of the two treatments will be planted first. Repeat this until all the plants have been allocated positions. If there are three treatments, use three different coloured marbles, and so on. This will ensure individuals from different treatments will be interspersed with one another.

4.5 - Consistency of planting is key
The best trials will be those that are the most consistent in how they source, install and monitor their plants. This will enable you to conclude with more confidence that any differences between treatments were a result of the treatment alone. There are several ways to achieve a high level of consistency.

Firstly, plants used in the trial should be of the same quality (e.g. size and structure) at the time of planting. A consistent pot size across your trial is essential unless you are using more than one pot size as a treatment type. Although plants can be of similar quality, no two plants are the same. If your trial species stock varies in size then consider randomising the size distributions as a treatment. To do this, first record the pot size, then simply measure the height (soil surface to highest growing point on main stem) and/or stem diameter (from a consistent height from the soil surface) of each plant, which will enable you to rank the plants based on their size. Depending on the number of treatments you have in your trial, these ranked plants can be designated to a treatment randomly using the marble method described above (see step 4.3).

Secondly, the preparation of the planting site shouldn't vary across your site (s) through space. As an example, when you are digging the holes in which to place the plants, make sure they have the same shape and dimensions. The accepted technique used in urban areas is that the hole should be three times as wide and as deep as the root mass of the plant, in a wok shape.

The purpose of the two points discussed above is to ensure the highest possible level of site and planting consistency is achieved. However, adhering to these practices will be invalidated if consistency is not maintained for the duration of the experiment. This means that maintenance regimes, such as water and fertiliser addition, need to be the same for all plants within your trial unless you have planned to compare an alternative maintenance regime as a treatment. Remember, it should only be the treatment you're testing that should vary between plants in your trial.

STEP 5. MONITORING

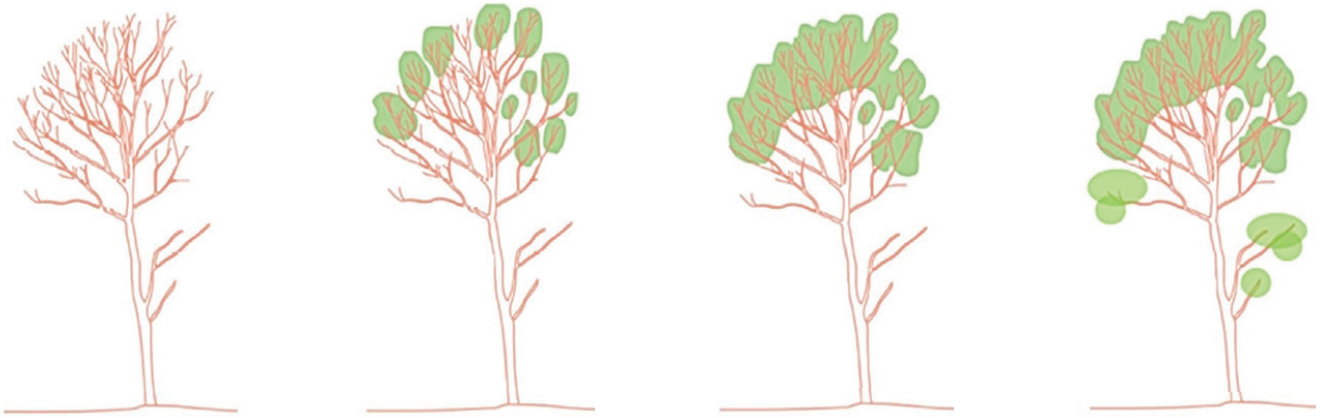
5.1 - Recording success and failure

The success of your trial species will be determined by its ability to survive and thrive beyond the establishment phase, ideally while receiving little or no maintenance. Assessing survival is self-explanatory but at times can be difficult to gauge accurately. This is because a plant may appear to be dead but is in fact just sitting dormant until more favourable conditions present themselves, at which time the plant can re-sprout and recover. Therefore, you must continue to survey plants that have previously been recorded as dead for the duration of your monitoring effort.

The survival of your trial species at the planting site is only part of determining whether the species is a suitable candidate to plant in your urban area. To complete the picture, you will also need to assess whether the species is growing and healthy. Two common non-destructive measures of plant growth are height and stem diameter at breast height (1.3 m above the surface of the soil). As discussed in the 'consistency is key' section (see step 4.4) above, you will have already measured these two growth parameters at the time of planting. Using these initial measurements, you will be able to track the growth of your trial plantings over time.

The survival of your trial species at the planting site is only part of determining whether the species is a suitable candidate to plant in your urban area. To complete the picture, you will also need to assess whether the species is growing and healthy. Two common non-destructive measures of plant growth are height and stem diameter at breast height (1.3 m above the surface of the soil). As discussed in the 'consistency is key' section (see step 4.4) above, you will have already measured these two growth parameters at the time of planting. Using these initial measurements, you will be able to track the growth of your trial plantings over time.

A good indicator of plant health is canopy density. The below easy-to-understand plant health scale based on canopy density can be used to guide you. A quick visual assessment using this scale will suffice, but for a more accurate measure of canopy density, a spherical densiometer (an instrument used to measure tree canopy density) can be used.



Dead:
No crown

Unhealthy:
1-70% crown

Relatively healthy:
71-90% crown

Healthy:
91-100% crown

5.2 - Time your monitoring

Monitoring is vital because it's when you get the return on your investment. However, it can be costly and time consuming if not done efficiently, so it's beneficial to do your monitoring at the most relevant and convenient times. For example, plantings are most vulnerable to mortality or declines in health during winter and summer when climatic conditions are at their most extreme. Therefore, monitoring at these times, or at the end of harsh times is more appropriate than monitoring in autumn and spring when conditions are milder. If you are trialling a deciduous species, monitoring should be carried out during the "leaf-on" stage of their annual growth cycle because visually assessing the health of a plant with no leaves is near impossible. Finally, to reduce the cost of monitoring your trial, try to schedule it at the same time as the routine maintenance is being carried out.

5.3 - Frequency of your monitoring

Plantings are most vulnerable to mortality or health declines during their initial establishment period, which is typically the first two years after planting. This means monitoring should be more frequent during this time (e.g. quarterly) but then can be progressively scaled back (e.g. yearly) through time. Before committing to planting a trial, note that it will likely involve at least a five-year monitoring effort.

5.4 – Document your trial using photos

There is no better way to remind yourself of how your trial has progressed over the long term than with photos. Think of them as your insurance policy. Photos should be taken at every stage of the trial from site preparation through to monitoring. It is important that your plants are photographed from the same position through time and that each photo has a date stamp, so that plant progress is easy to track.

04.
DATA SHARING & ADDITIONAL RESOURCES

STEP 6.
DATA SHARING

6.1 - Sharing is caring

To help inform the selection of appropriate species for future trials, it is important that you share the findings of your trial. This can be done at by either sharing it with the Which Plant Where team or you can register your trial in the TreeNET case study portal, which will give users the basic information about your trial as well as your contact information, so they can make enquiries.

By feeding information back into this knowledge base, you are enabling it to grow, which will mean the next people to trial a species will have a greater amount of information on which to base their species selection. This will ensure future street tree trials do not reinvent work already done but rather value add to it.

ADDITIONAL RESOURCES

TREENET Street Tree Species Trials Research: Street Tree Species Trials

Which Plant Where Online plant selector tool (Release date OCT 2021): Which Plant Where

Nursery Tree Stock Quality: Insights into Standards for Nursery-Grown Tree Stock

Don't Buy It – Don't Plant It! Applying AS 2303 Tree Stock for Landscape Use

What is Tree Resilience and How is that Reinforced in the Production Nursery?

WhichPlantWhere

Appendix 3:

Best practice guidelines

3.2 How to successfully establish your new trees

https://whichplantwhere.com.au/resources

How to successfully establish your new trees

By Gwilym Griffiths, November 20th, 2021

Planting trees represent a significant investment so it is critical that the process is done right! With increasing impacts from climate change, including variable rainfall and increased heat, it is no longer good enough to just plant a tree and hope for the best.

Successful tree planting and establishment can be divided into **4 key success factors**, 1. Planning and species selection 2. Quality stock 3. Correct planting 4. Establishment Maintenance, see figure 1 for a graphic representation of this.

Each of these key success factors are equal in their importance, if one step is ignored the whole process can be jeopardised. This can be described as the 'law of the minimum' which states that succes is not dictated by the process itself by the weakest link in that process (greatest limiting factor). The process should also be underpinned with good **communication** and **monitoring** throughout all stages to ensure that all stakeholders understand the process and that each stage is monitored for quality and or correct practices.

Image courtesy: Gwilym Griffiths

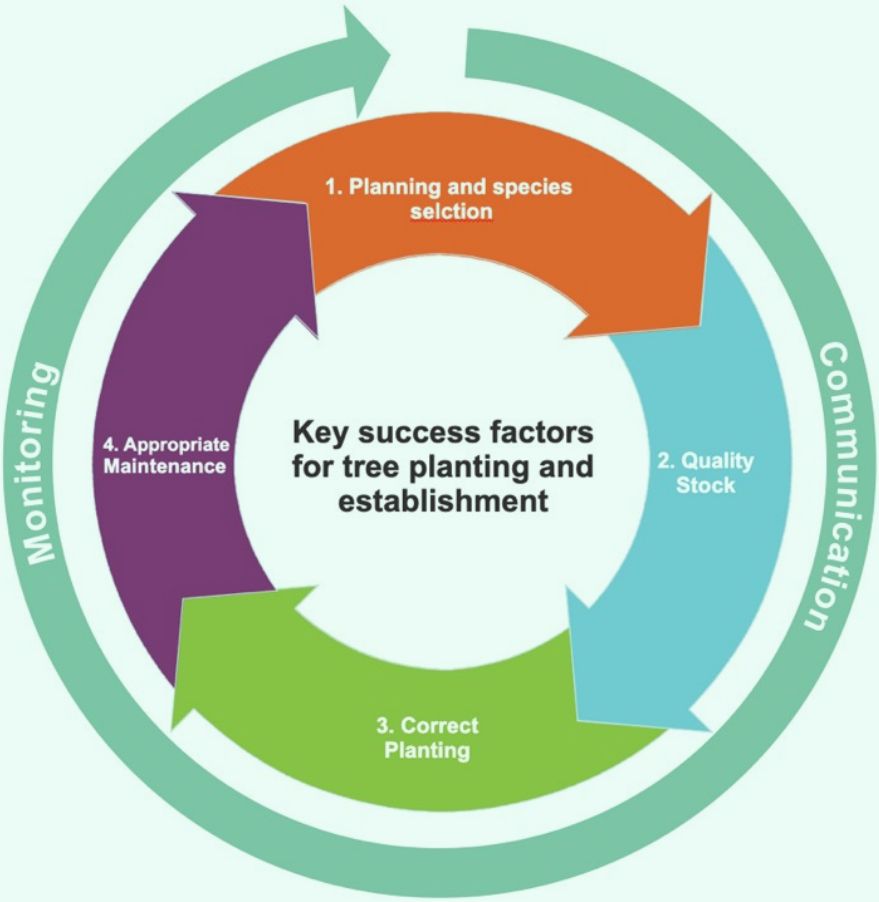


FIGURE 1 Representation of the key success factors for tree planting and establishment, critical to each stage is good communication with stakeholders and monitoring of outputs.

1. PLANNING AND SPECIES SELECTION

LOCATION - 'get the site right', especially if it is a street tree as there are usually many competing elements in the streetscape and it is essential that the location is suitable for the chosen tree. The tree will hopefully be in this location for many decades and allowing enough space for it to develop, uninhibited, to its full maturity is important. Consider proximity to services (above and below ground), distance from buildings and other built infrastructure. Sight lines and offsets from intersections are also important from a traffic safety point of view, in most scenarios' trees will need to be planted 10m away from intersections. Refer to your state or local road authority for guidance on this.

TIMING - Planting time matters! Make sure you are planning your planting program to align with the best season to plant. Autumn is generally the best time to plant due to maximum root growth and caliper growth during this time. Planting during autumn will ensure that when it comes to the following summer that your trees have had time to establish a root system and will require less watering and maintenance during the summer heat. Spring is also fine to plant but trees are generally focusing on foliage growth at this time and may not establish roots as readily in time for the harsh conditions of summer.

SOIL VOLUME – does the location have enough available soil volume to sustain the tree into maturity? Trees will only grow to their full potential size if there is the soil to support sustained growth. There are numerous methods available for calculating soil volume, one of the earliest methods was developed by Lindsay and Bassuk which calculated a minimum required soil volume based on the projected canopy area of the mature tree (0.6 x m^2 projected canopy). More recent methodologies have been developed that utilise tree height instead of width. Simon Leake and Elke Haege have developed the 'Soils Volume Simulator' which incorporates tree height and other environmental and growing conditions to formulate required soil volume, it can be viewed here https://www.elkeh.com.au/soils/.

SOIL QUALITY – Take a soil sample! Look at your soil to see what properties it has. Is it a heavy clay or well drained sand? Do you need to incorporate any soil additives to improve soil quality? Soil science is a complex field and you may require the expertise of a soil scientist to provide the best advice for your site. What is the drainage like, will you need to incorporate additional drainage into the tree pit design. These questions are important to consider early on in the planning phase so that allowance can be made during planting.

SPECIES SELECTION – 'The right tree for the right location'. Selecting the right tree is essential for the success of the planting. Factors to consider include soil type, drainage, climate, available water and available space (above and below ground). Maximise each location by selecting the biggest size tree suitable for that location, there is little value in planting and small Blueberry Ash in a location that could sustain a large Eucalypt.

Selecting a species that will be suitable to future climate extremes is also essential to consider, our cities are getting hotter and selecting the right species will mean the difference between success and failure. The 'Which Plant Where' web tool enables this enhanced decision making and is a valuable resource to ensure success of your planting. Refer Also to the article '*Best practice species selection*' in the resources page of the Which Plant Where website for more information.

2. QUALITY STOCK

Buying a tree is a long-term investment. Trees are a structural asset that require structural integrity to perform, this integrity starts in the nursey and if the quality isn't right when planted it will never be right. Poor quality trees might grow well in the early years but if the structure isn't right, either below or above ground, there will be issues later on.

The tree itself is generally the smallest cost of the project when compared to labour costs to plant and maintain the tree, however the quality of the tree itself can make or break the project. To buy anything other than the best available tree is a false economy.

There is one way to ensure your tree is good quality, ensure it has been grown in accordance with **AS2303:2018 Tree stock for landscape use**. This standard has been developed over many years and is tried and tested in the industry. Go to the nursery before you purchase your trees, talk to the grower and find out what quality of trees are available.

"You either plant trees that have been grown to AS2303 or you don't plant at all. The cost of the tree is generally a relatively small % of the total costs of new trees in our urban landscapes. Design costs, site works, planting and establishment costs etc. will form the bulk of the costs involved. To plant sub-standard trees is to risk all those other costs, the time lost when new trees fail and the costs involved with replacing them."

Ross Clark

Assessing stock quality prior to purchasing your tree is important. It is not good enough to simply specify the standard without checking compliance with it.

The 'Tree Stock Standard Project', a collaboration between Hort Innovation, Nursery and Garden Industry Australia and Western Sydney University, developed a simple to follow non-destructive method of assessing tree stock against the standard, it considers a 'Preferred Percentile Range' for size index values that account for stem diameter, height and container size. This assessment method can be found here:

www.westernsydney.edu.au/__data/assets/pdf_file/0011/1484282/HIE-card-A5.pdf

One element on tree quality that is often overlooked in the nursery industry is the staking of young trees directly to the stem, see figure 2 below. This promotes tree height but not stem diameter, in extreme cases once the bamboo stake is removed the tree will fall over as it has not developed its own strength, this is especially true with eucalypt species. Trees are opportunistic and will not develop strength or lay down wood where they don't need to.

FIGURE 2 Image of a tree that should never have gone in the ground. There are two key things wrong here, the first is the girdled root system which will never repair itself and will eventually strangle the tree and the second is the bamboo stake tied directly to the stem, which promotes tree height but not stem diameter and therefore structural weakness. (Image credit: G.Griffiths)

3. CORRECT PLANTING

The correct way to plant a tree is often not clearly understood, there are several key elements to consider when planting the tree, they are; (refer to figure 3 tree planting detail for a graphic representation of this information)

SAFE HANDLING OF TREES AT DELIVERY - Move trees by using the handles on the bags / pots. Avoid handling or lifting via the trunk as this can damage fine root systems or ringbark the soft tissue on the tree trunk. Machine handling is recommended for larger stock > 100L as long as majority of weight is taken by the rootball. Lifting via single 'choker' slings around the trunk is not advised. Crossing slings should be placed around the rootball to take the weight of the tree and a secondary 'balancing' sling used around the trunk with protection such as hessian

LOCATION AND SIZE OF HOLE - The tree should be located in the centre of the hole with adequate setback from roads or buildings. The hole should be excavated to **three times** the diameter of the container, this is important to provide enough 'good' soil around the rootball to allow for unimpeded root development during the early life of the tree – this early root development is import to set the tree up for the future by ensuring an even structural root crown is established.

The tree should be planted facing the same direction as they were grown in the nursery. Most good growers mark the north point on the bag of tree when it is supplied – this north point should be replicated on site.

DRAINAGE - Ensure the planting hole is free draining and does not retain excessive water. Correct if necessary. Root systems will suffocate and die if the planting hole retains water due to the exclusion of oxygen and creation of toxic anaerobic conditions.

ROOT BALL HEIGHT AND BASE OF HOLE - The root ball should be placed onto a **consolidated base** at the bottom of the planting hole, this ensures the weight of the tree itself will not cause subsidence and affect the level at which the tree is planted. The top of the root ball should be level with the surrounding ground. If the rootball is too low in the ground this may lead to collar rot, if the root ball it too high in the ground this may cause the root ball to dry out.

SOIL IMPROVEMENT – A healthy soil provides for optimum tree growth and the successful establishment of the tree. Ideally you have identified the necessary soil improvement required for the site during the planning process. Often with planting in urban areas the soil can be compacted or high disturbed. Effort should be placed on soil decompaction and consider adding composted organic matter to improve structure and soil composition.

ROOT PRUNING - Prior to planting the root ball should be inspected for any pot bound roots, these roots should be cleanly pruned with a sharp knife or secateurs to promote even root extension growth. Roots that are circling in the pot will never straighten themselves out in the ground and will generally just keep circling, this is why this step is so important. Most good nurseries ensure this step of root pruning is done prior to delivery so it is not forgotten on site. Well grown stock will not require much root pruning however it is still likely to be needed to some extent.

STAKING - 'Protective' staking is encouraged to provide a buffer around the tree to prevent any damage, especially in highly urbanized areas. The stakes are not there to provide support and if the tree is not self-supporting is should not be planted. 'Figure of eight' strapping around the trunk is not encouraged as it does not allow for enough movement and can wear away at the outer cambium of the tree. If the tree arrived with nursery stakes directly against the stem (which they should not) these need to be removed before planting. If the tree does not support itself after the stake is remove then it should not be planted as it does not conform to AS2303.

WATERING - The tree must be watered in the pot prior to planting to ensure the root ball is soaked and immediately once planted in the ground. The formation of a 'bund' or 'bermed dish' close to the edge of the root ball with assist with establishment watering. See below for more information on ongoing establishment watering.

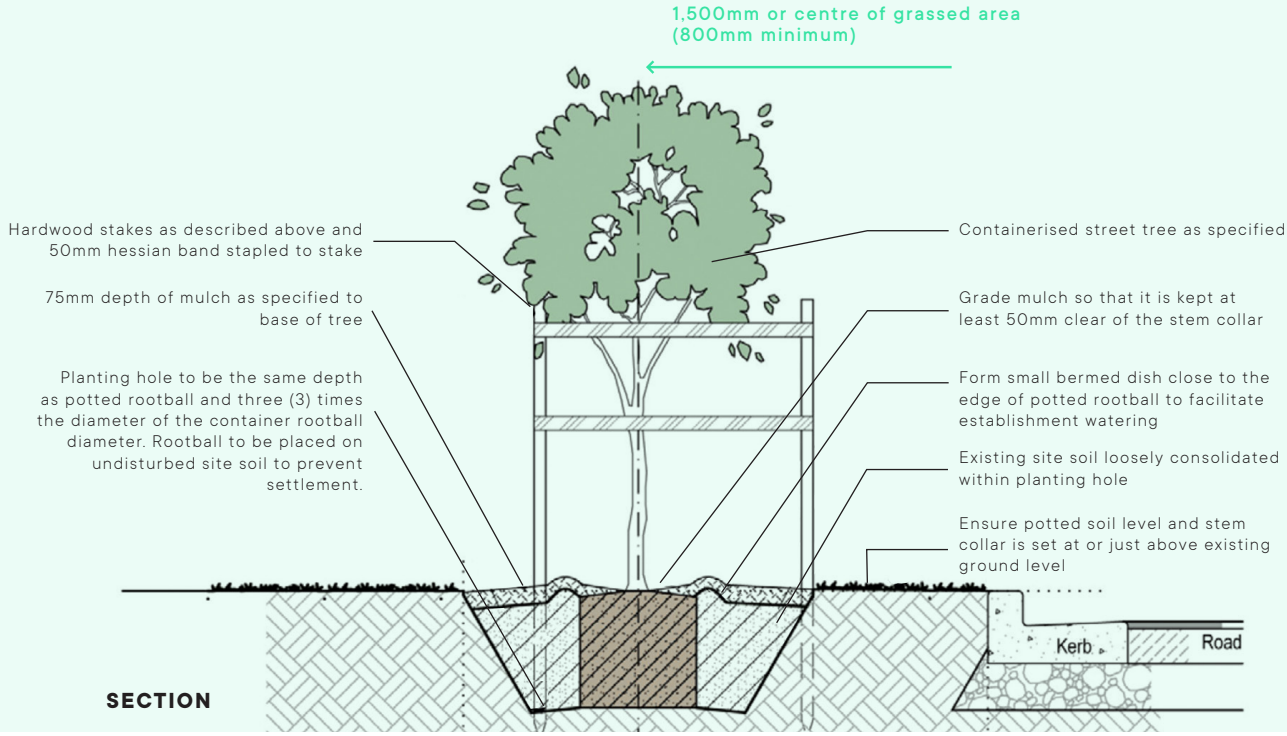


FIGURE 3 The correct way to plant a tree. Note the level of the rootball in relation to the surrounding ground and the consolidated base on which the rootball is placed. (Image credit: Arterra Landscape Architects)

MULCHING – mulch is a trees' best friend and should be applied immediately after planting. It will help retain moisture in the soil and provide organic matter to replenish the soil as it breaks down. The best mulch is the 'leaf mulch' that comes from the back of a chipper as it has a variation of particle sizes that allow for aeration and different rates of decomposition. Ideally the mulch is not green and has had time to compost somewhat before it is placed around the tree.

4. ESTABLISHMENT MAINTENANCE

It is essential to provide a tree establishment period for newly planted trees, significant effort has gone into planting the tree but the job isn't finished yet! The duration of the established period can vary and is influenced by climate and the size of tree at the time of the planting. The larger the tree at the time of planting the longer the establishment period. Ideally the establishment period is somewhere between 12 and 24 months. This obviously has financial impacts but this should be factored in during the planning phase - if you can't afford to establish the number of trees you want to plant then plant less trees. In some cases, less is more and the allocation of the correct resources is critical.

WATERING – is undoubtedly the most important element of establishing a newly planted tree. Planting a tree and relying solely on rainfall is not an option, especially with large tree stock.

A new tree can only access moisture that is within its rootball. The amount of water is determined by the size of the root ball and is generally 20% of root ball volume, so for a 45L tree it would be a volume of 9L of water at each application, this can vary depending on soil type. Frequency of watering is a sliding scale and is dependent on the time of year, generally less in cooler months and more in hotter months, depending on time of year the tree is planted. The tree will need more water directly after planting and less as the tree establishes.

It is important to check drainage each time you water the tree, if the tree pit is not draining there could be issues and watering may need to be adjusted or the tree pit modified to improve drainage.

Ross Clark has developed a comprehensive guide to watering new trees which is available here https://www.treesimpact.com.au/articles/watering-newly-planted-trees

Other elements of tree establishment maintenance that should be undertaken during the establishment period include the following:

- Weeding and rubbish removal from tree surrounds
- fertilising
- pest and disease control
- adjustment, removal or replacement of protective staking
- formative and selective pruning to AS 4373
- mulching to maintain and reinstate to depth specified

ACKNOWLEDGEMENTS

We would like to acknowledge Ross Clark from Trees Impact for his contribution to this article.

Appendix 3:

Best practice guidelines

3.3 How to measure your urban forest

https://whichplantwhere.com.au/resources

Which Plant Where

How to measure your Urban forest

A best practice guide to establishing a tree inventory

NOVEMBER 2021

ACKNOWLEDGEMENT OF COUNTRY

We acknowledge Aboriginal and Torres Strait Islander peoples as the First People and traditional custodians of the land and waters of this place. We express our gratitude in sharing this land, our sorrow for the personal, spiritual and cultural costs of that sharing, and our hope that we may walk forward together in harmony and the spirit of healing.

We acknowledge the importance of Aboriginal custodial and cultural connection to place, which is embodied in the term 'Country'. 'Caring for Country' is used to describe ongoing stewardship of and responsibility for the land and seas by First Peoples.

We recognise the ecological knowledge of Aboriginal people that has developed from thousands of generations of careful, sustainable land management practices. This knowledge can be harnessed to protect and enhance our urban forest, water, biodiversity and soil. There is an opportunity for Aboriginal values around Country to co-exist alongside scientific and mainstream land management approaches.

FIGURE 1 Welcome ceremony at Macquarie University – situated on the land of the Wallumattagal clan of the Dharug Nation *(Image owned by Macquarie University)*

WHICH PLANT WHERE

is a culmination of 5 years of research investigating which horticultural species will survive in Australian urban landscapes, not only now but under future climates. The project is underpinned by the latest scientific evidence, providing growers, nurseries, landscape architects and urban greening professionals with the integrated tools and resources needed to develop resilient and sustainable urban green spaces for the future.

Authors: Gwilym Griffiths (Good Canopy Company). Manuel Esperon-Rodriguez (Western Sydney University), Paul D. Rymer (Western Sydney University), Sally A. Power (Western Sydney University) & Mark G. Tjoelker (Western Sydney University), Leigh Staas (Macquarie University).

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ORGANISATIONS

CONTENTS

01. INTRO

02. BEFORE YOU GET STARTED

03. PROCESS

04. DATA SHARING AND ADDITIONAL RESOURCES

01. INTRODUCTION

Trees provide a multitude of ecosystem services for our cities and their inhabitants, from temperature reduction to improved health and wellbeing. To ensure these services are maximised, cities require healthy, functioning and diverse urban forests. Increased temperatures and shifts in rainfall patterns due to climate change are putting pressure on our existing urban forest, and some species that have succeeded in the past may fail to do so in the future. It is vital that we put resources towards maintaining and monitoring our urban forests to ensure they are resilient and can adapt to climate change.

Good data is critical for decision-making and strategic planning in any organisation. It can provide valuable insights into the quality and value of an asset and uncover underlying issues or barriers to success. This approach also applies to our urban forests. To maximise the environmental, economic and social return of these natural assets, we need to know what we have, how it performs, and what resources are required to maintain them through the life cycle of these assets. It is crucial to identify and quantify successes and failures in urban settings as this can help policymakers and urban forest managers to optimise use of resources and minimise losses when investing in urban forestry programs.

This best practice guideline provides an easy-to-follow process for undertaking and implementing a best practice tree inventory for your urban forest. This guide aims to assist local councils to apply basic principles consistently so that:

- a standardised measuring and monitoring method can be implemented across multiple organisations
- tree species' suitability to changing local conditions can be tested, measured and evaluated
- councils can collaborate, and results can be compared among different locations
- knowledge can be shared to increase species diversity and enhance urban forest resilience
- resources can be maximised by collecting key data according to specific objectives

Most Councils are recognising trees as assets in their operational planning and maintenance programs and manage their trees with a 'whole of life' asset management approach. This ensures that risks from trees are managed and that costs associated with maintaining trees over their life cycle are accounted for. This asset management approach can be further enhanced by adding measurement and monitoring to the cycle. This is illustrated in Figure 2.

FIGURE 2 The strategic 'whole of life' tree asset management cycle.

"You need to know what you have to know how to manage it."

02.
BEFORE YOU GET STARTED

It is essential to first identify where you are in your urban forest journey. Have you just begun and need to get a basic understanding of what it is you are managing, or are you part of the way there and already have some of the information you need to start making strategic decisions? To establish this, the key questions to ask are generally why, what and how?

Why

Why are you measuring the urban forest and who will be using the information?

Start with the Why! This will help you define the outcome. What is your vision? What are your goals? Key to these questions is the principle that 'you need to know what you have to know how to manage it'. **Some of the key reasons to undertake an inventory are to:**

- Identify and mitigate risk
- Plan future maintenance and renewal programmes including budgeting
- Inform future strategic directions and planning

Good data is a prerequisite in planning for and making sound management decisions. The more data you have on your urban forest, the better the decision-making capabilities. Also, consider who will (or should) be using the information within your organisation. Key users of the information are usually your operational tree management teams, strategic planning teams and environment/ resilience teams.

What

What are you measuring and what will you be doing with the data now and in several years' time?

What are your metrics? What information are you going to collect to inform your work? Have you established a list of requirements? These questions are really important to determine upfront. Consider what you are using the information for and how you plan to use it in the future. This is essential in terms of repeatability and accuracy, as you want to be able to compare 'apples with apples' when you repeat the process down the track.

How

How will you be undertaking the measurement and how often will you be doing it?

There are many ways to measure the urban forest. The majority of urban forest measurement is conducted by ground-based field surveys but other approaches exist including windshield surveys and remote sensing methods. The approach to data collection must be considered in the context of the desired outcomes, as not all approaches can provide the same level of information.

To gain accurate insights and to be able to answer your questions correctly, you need a robust and systematic data collection method. The more you can repeat the measurement, the more accurate your data set will be.

Once you determine your why, what and how, it's time to get stuck into it. There are three main steps in the process;

Measure
Assess your assets

Monitor
Analyse your data

Maintain
Keep your data up-to-date

03.
PROCESS

Measure

Measure what you have.

A tree inventory can be the most powerful and accurate method of collecting and analysing urban forest data in the public realm, including metrics such as species diversity, tree health and condition, age and useful life expectancy. There is limited capability to measure these metrics from any other method.

Inventory data can either be collected over time or in one bulk acquisition. Data collected over time (ad-hoc) can pose issues with accuracy and consistency unless the parameters are well defined upfront and the inspections are undertaken by similarly qualified personnel using a standardised methodology. Bulk acquisitions - data collected as part of one process or project – are generally more accurate as the information is usually collected with a clear set of specifications and by a select group of assessors working to the same objective. The cost of bulk acquisitions can be a limiting factor for some organisations.

Traditionally these inventories are collected by qualified arborists conducting ground-based assessments on individual trees - this method is the focus of this report. However, it is worth mentioning new methodologies are emerging that utilise aerial imagery and LiDAR technology that can collect large data sets of tree information with high repeatability. LiDAR sensors can generate three-dimensional point clouds of trees, from which data on structural variables, such as tree height and crown width, as well as species identity and georeferenced location, can be extracted. LiDAR sensors can be attached to an aerial platform (e.g. fixed-wing aircraft), a terrestrial platform (tripod), or a mobile platform (e.g. car). This approach is fast and generally cost-effective when compared to traditional ground-based inventories, with the added advantage of being able to acquire data on both public and private tree assets. However, at the moment this method cannot replace the qualified eye of an arborist to assess variables such as tree health, structural defects or pest and disease impact. It is currently used as an enhancement to a traditional inventory or an excellent starting place for Council to to collect tree inventory data – watch this space.

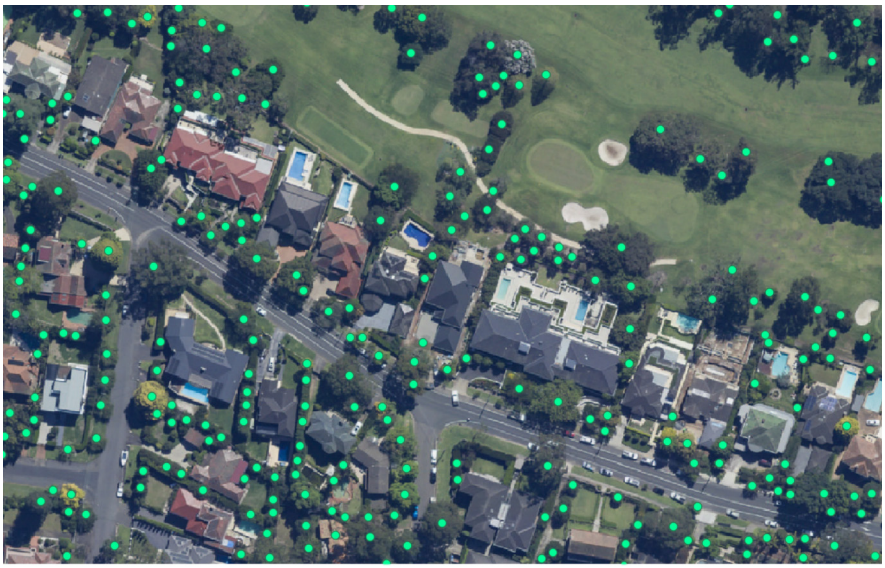


FIGURE 3

Example of inventory location data generated from aerial imagery. Each green dot represents an individual georeferenced tree that can be linked to information on that tree such as species, size and condition. *(Image courtesy ArborCarbon)*

WHAT INFORMATION DO I NEED TO COLLECT?

You will need to identify the categories of information required, and how that information will be accessed and used in the field. The tree assessments should be carried out by a minimum

Australian Qualifications Framework Level 5 (AQF5) qualified arborist. A minimum set of information must be collected to ensure the data is valuable and provides the required metrics.

This basic information could include:

- location of the tree (by GPS and street name and building number)
- botanic name of the tree species (common name is less important)
- diameter of the tree's trunk at a standard height (DBH)
- tree height and canopy width
- condition of the tree (good, fair, poor, dead/dying)
- pest and diseases present
- useful life expectancy (ULE)
- risk profile of the tree (using an industry recognised methodology)
- maintenance requirements of the tree
- location and type of potential planting sites for new trees…

The list goes on and is generally only limited by what your organisation is financially resourced to collect or what your asset system/ software can accommodate. We have provided an extensive list of possible attributes you could collect in Section 4 - Data sharing and additional resources', prioritised by 'essential to have' and 'nice to have' data fields.

The addition of site metadata, such as photos of the site, slope, aspect, soil attributes (e.g. drainage, type or texture, compaction and nutrient levels), infrastructure damage, distance to roads and buildings (among other things), provides useful information for further interpretation and analysis. Data text fields (i.e. large blocks of text) should be avoided, and automated lookups should be utilised to allow for more detailed analysis and interpretation.

FIGURE 4 Collecting tree inventory data *(Image courtesy Homewood Consulting)*

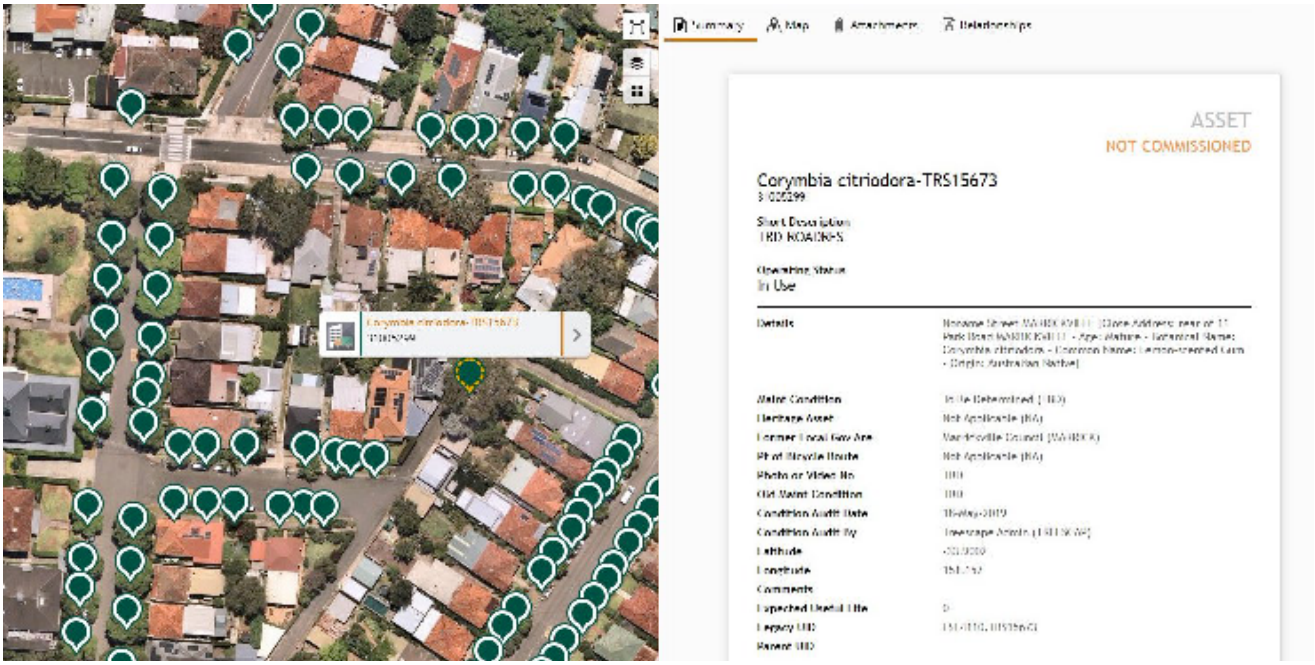
INVENTORY SYSTEMS

Inventory database systems (software) can vary from a basic spreadsheet to a customised tree asset management platform. It all comes down to useability, function and cost. A spreadsheet is fine if you are just using the data for analytics, but from an asset management and operational programming point of view, custom tree asset management systems offer a far superior level of functionality, including spatial mapping; see examplebelow in Figure 4.

Several companies in the market offer bespoke asset management systems specifically designed for Council tree operational management. These are worth looking at, as much of the hard work in defining data fields and enabling GIS capability is done for you. However, if you are with a Council, you may have an existing asset management system that the organisation uses for other assets such as roads and footpaths, that you are required to use.

It is important with these systems that there is flexibility with custom fields to allow for treespecific data to be collected. The benefit of having an existing Council system is that you can generally get support from other asset teams, and the system is usually integrated with other reporting systems.

FIGURE 5 Example image of a Council asset management system *(Image courtesy Inner West Council)*



The ability of the asset system to export the data into programs that can display the information in appealing ways for decisions makers and the community is an added feature that is worth considering. Quite often these asset systems sit behind closed doors and the power of communicating the data is not able to be realised. Extras such as dashboards and other visualisation tools can also be useful for community engagement; some examples of where this has been done well include platforms provided by Lane Cove Council https://au.pg-cloud.com/LaneCoveNSW/ and the City of Melbourne http://melbourneurbanforestvisual.com.au/.

WHERE DO I START?

Establishing an inventory can be costly for an organisation and collecting a full range of data in one bulk acquisition may not be possible. There are generally two approaches to this problem. One is to only collect basic information, thus reducing the time it takes to complete the inventory. The other is to focus on specific areas, such as town centres or precincts, and collect a full range of information. Each method has its pros and cons.

Collecting only basic information (level one assessment) will limit the effectiveness of the data collected and may reduce the viability of the inventory. However it is a reasonable place to start and will provide you with some key metrics to start analysing and understanding your urban forest. The data can also potentially be added to as time goes on to further enhance the functionality of your inventory. For example, an aerial imagery tree inventory, as mentioned above, could be added later.

Undertaking a partial inventory for target areas or key precincts such as town centres or main roads can be a worthwhile exercise from a risk management point of view. With this approach you can focus your tree maintenance resources or high target areas or areas with higher risk trees. This method however provides reduced capability for meaningful analysis of key urban forest metrics such as species diversity, age distribution and ULE.

There is a scale of economy that comes with the bulk acquisition of tree inventory data, which is usually realised at tree numbers above 10,000. Project start-up costs are a significant portion of the cost to acquiring bulk acquisitions and the more trees in the project the better the per tree rate. Meaningful cost efficiencies can be achieved by combining forces with adjoining Councils to put out a larger contract for an inventory.

Monitoring

Monitoring involves repeatedly measuring over time in order to observe and analyse changes in your urban forest.

Monitoring enables you to track the progress and condition of your tree assets over a period of time and implement adaptive management to address any issues as they arise. Monitoring also enables the measurement of progress against your strategic goals and objectives, for example as defined in a strategic document such as an Urban Forest Strategy (if your organisation has one). As you implement planned actions, such as tree planting and maintenance, monitoring will allow you to see if progress is being made against your strategic goals – this is known as Strategic Asset Management.

Knowing how to analyse your data is the key to harnessing its potential. Monitoring your urban forest is key to successful planning for your operational maintenance and planting programs. Your urban forest data provides you with the information required to build a business case, for example to apply for more resources within your organisation, or to access grants and funding from state government.

WHAT DATA TO LOOK FOR

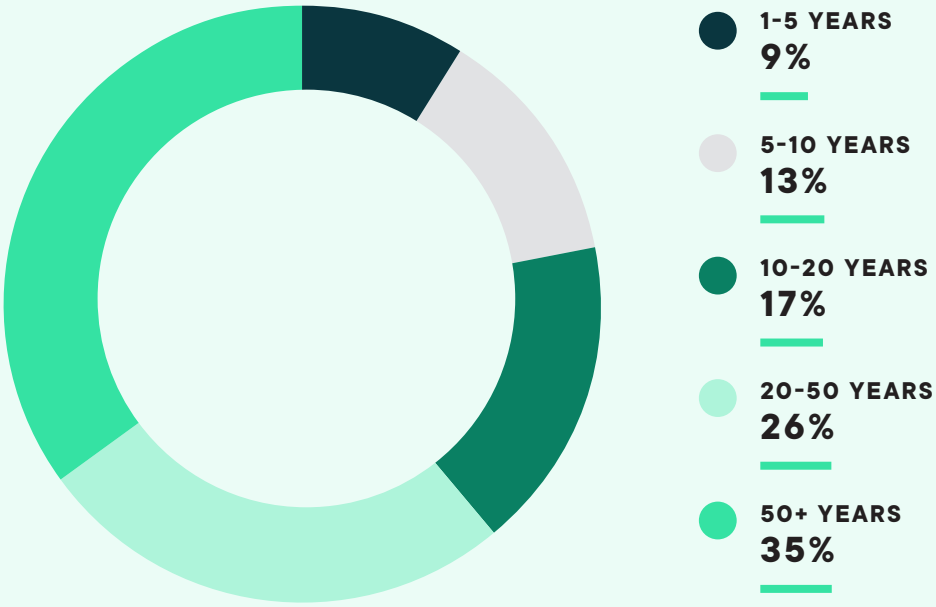
When analysing your data there are some key areas to focus on to allow for informed decision making. Some of these include:

SPECIES DIVERSITY What percentage of your urban forest is represented by one particular genus or species? What is your proportion of native vs exotic? A highly diverse urban forest is a resilient urban forest. Low species diversity will leave your urban forest vulnerable to pests and diseases and future climate scenarios. If you have low species diversity you should focus on diversifying your planting palette and avoid planting species that are over represented. A general rule of thumb is that it is best to have no more than 10% represented by one species, no more than 20% represented by one genus, and no more than 30% representation from a single family.

AGE DISTRIBUTION AND USEFUL LIFE EXPECTANCY What is the age class distribution of your urban forest? Do the majority of your trees sit within the mature age category? It is best to have an even distribution of tree age across your urban forest, allowing for succession of the canopy through the age class categories. Trees should be managed to their full ULE to maximise their benefits – this is often a fine balance with effective risk management.

If you have an over-mature urban forest you will need to plan for the allocation of resources to manage the risk of these aging trees and to increase planting programs to tray and diversify the age distribution – it is likely you will inevitably see a decline in canopy as the over-mature trees eventually require removal.

FIGURE 6 Example of urban forest data presented graphically to represent Useful Life Expectancy (ULE).



RISK PROFILE how many high-risk trees do you have that need to be more frequently monitored or removed and replaced within a determined timeframe? Budgets should be in place to effectively implement these removals and allow for replacement trees to be planted. Analysis of risk profiles allows you to plan ahead and stage your programs based on risk ie high risk trees to be removed first and low risk trees last. A recognised risk methodology such as Quantified Tree Risk Assessment (QTRA), Tree Risk Assessment Qualification (TRAQ) or VALID should be utilised.

HEALTH AND STRUCTURE What is the condition of your urban forest? Is further resourcing needed to improve your maintenance program and effectively maintain the health and condition of your trees? What are the contributing factors to tree condition, is climate change impacting species' resilience and do you need to consider planting other, more resilient species?

TREE SIZE Measuring the various elements of tree size, such as canopy width, height and trunk diameter helps us learn more about the tree's ability to provide benefits. This information can inform calculations to provide tree benefit values such as those provided by 'i-tree' including carbon sequestration value, stormwater abatement value, ecological services and monetary value.

RECORDING SUCCESS AND FAILURE

Recording data on successes and failures can assist in improving species selection and in the development of management plans for climate resilience of your urban forest. Currently, many organisations focus on successful plantings and only record the tree in the inventory once it has established. Collecting data on failures, including the reason for failure (e.g. incorrect species selection, pest or disease, vandalism, lack of water, competition with infrastructure, etc) can provide valuable information for management.

Failure can occur at different times during a tree's lifespan and can include post- planting, during the establishment period and times of stress (such as drought). Notably, the early stage of a tree's life (after planting and early establishment) is the most vulnerable and has higher mortality rates. Thus, monitoring and collecting data on failures during this time is crucial to identify resistant and vulnerable species.

Collecting tree and branch failure information, including a description of the nature of the failure, the condition of the tree, and pre-existing structural defects that may have contributed to the failure (inclusion, decay, etc), can assist in developing species' profiles and 'failure potential' data. This information can assist with long term maintenance plans and in future species selection.

FIGURE 7

Recording branch failures is important to build 'failure potential' data profiles *(Image G.Griffiths)*

Maintain

Your data is only as accurate as the last time you updated it. For any tree inventory database to be successful, it is essential that there are adequate resources and processes in place to ensure it is well maintained and regularly kept up to date.

Inventory data maintenance should be embedded in every process associated with tree maintenance and planting. Every time a tree is inspected, pruned, planted or removed, it should be updated in the inventory. This is called 'live' database management. The inventory should not be a static entity, it has to be continually maintained to stay relevant.

Quality control is also important, as you want to make sure the information you are collecting is correct and accurate. This level of quality control is often achieved by limiting the number of users in the system and by ensuring that each user is qualified and trained in how to use the system.

FIGURE 8

Maintaining your tree inventory data is important *(Image courtesy Homewood Consulting)*

PROCESS

In Councils with tree maintenance programs undertaken by contractors, it is advisable that tree maintenance contracts are updated to: (1) require the Council's contractor data to be integrated with the asset management database; and (2) require the Council's contractor to update tree records as they undertake works on individual trees. This should involve not just updating the database with the works they are undertaking at the time but also updating key data fields such as height, condition, DBH, risk rating, etc.

Establishing a forward inspection program to have your trees assessed on a regular basis is the most effective way to maintain your database and address tree risk. This involves a proactive scheduled inspection of your trees, often on a precinct basis, to assess any potential hazards and update key inventory date fields. Inspections are then followed up with scheduled maintenance if required. The aim is to assess the potential risks before an issue arises and undertake maintenance works if needed – this is called proactive tree maintenance and the best way to manage your trees to their full ULE.

Funding and resourcing of this level of inspection and data management can be an issue for some Councils, however the cost savings associated with maintaining the data rather than collecting it all over again are worthwhile.

The operational tree management teams within Council should become 'owners' of the system and ensure it is maintained as a live database.

04.
DATA SHARING AND ADDITIONAL RESOURCES

Data sharing

Sharing is caring. To help inform the selection of appropriate species for future plantings, it is important that you share the findings of your monitoring.

This can be done at a local-scale when you are deciding what species to plant via the networks that shared their knowledge. By feeding information back into this knowledge base, you are enabling it to grow, which will mean the next people to plant a species will have a greater amount of information on which to base their species selection.

Sharing results can be an advantage to those undertaking new plantings, to help them avoid reinventing work already done or to consider how to value-add to work already done. Making your monitoring data available for collaborators in different localities can help to evaluate factors contributing to good/poor performance, including identifying climate resistance/ vulnerability. Collaboration among organisations will provide greater insights to improve urban forest management and planning.

An example of where this collaboration has come into practice can be seen here;

OPEN COUNCIL DATA STANDARDS

standards.opencouncildata.org/#/trees?

TREENET STREET TREE TRIALS

treenet.org/research/street-tree-species-trials/

OPEN TREES DATABASE

opentrees.org/#pos=1/-37.8/145

Additional resources

The table below outlines the ideal data fields for collection when undertaking an inventory.

They are arranged by 1) Location Details; 2) Tree attributes; and 3) Tree Maintenance. An asterisk (*) against a field suggests that this is essential/ minimum requirement data that should be captured.

LOCATION DETAILS	Type of data to be entered
Asset Number*	Free entry
Status	Current / removed
House No*	Free text entry
Street*	Load all streets in Council Area
Suburb*	Load all Suburbs in Council Area
Maintenance Precinct	Pre-determined
Land use	Park/ Street/ Reserve/ Carpark/ Property
Park/ reserve/ carpark name	Load all parks and reserves in LGA
GPS Location*	X, Y Coordinates and/or Lat/long
Planting scenario	Grass/ concrete pit/ other
Soil compacted	Yes/ No
Power lines	None/ ABC/ LV/ HV
Surrounding infrastructure damage	Yes/ No
Photo	Attach

DATA SHARING AND ADDITIONAL RESOURCES

TREE ATTRIBUTES	Type of data to be entered
Botanical Name*	Species look up values to be provided
Height (m)*	Free entry
Canopy width (m)*	Free entry
Height to base of canopy (m)	Free entry (needed for i-tree assessment)
Percentage canopy missing (%)	Free entry (needed for i-tree assessment)
Diameter Breast Height (DBH)*	Free entry
Diameter at Base (DAB)	Free entry
Age*	Young/ Semi Mature/ Mature/ Over Mature
Visual Condition*	Good/ Fair/ Poor/ Very Poor/ Dead
Structure*	Very poor/ poor/ fair/ good/ has failed
Defects*	Included bark/ previous branch failure/ epicormic growth/ bracket fungi/ mechanical damage/ cavity (decay)/ split or crack/ hanger/ crossing branches/ dead wood/ excessive kino or resin

TREE ATTRIBUTES	Type of data to be entered
Pest and disease*	Termites/ borer/ wax scale/ stink bug/ sooty mould/ leaf chewing insect/ sap sucking insect/ myrtle rust
Hollows or nests	Yes/ No
Habitat tree (artificial hollows installed)	Yes/ No
Useable Life Expectancy (ULE)*	Zero/ up to 5/ 6 to 10/ 11 to 20/ 21 to 50/ over 50
Whipper snipper damage	Yes/ No
RISK ASSESSMENT*	Use your organisation's adopted tree risk methodology (Below are the required fields for QTRA)
Target	1 to 6
Size	Property/ 1 to 4
Probability of Failure	1 to 7
Risk of Harm Value	*Formula value linked to above*

TREE MAINTENANCE	Type of data to be entered
Tree maintenance required	None/ Annual inspection/ Branch pick up / Broken branch/ hanger/ Crossing branches/ Canopy lift (footpath/road)/ Property clearance/ Climbing inspection required/ Codominant reduction / Create habitat tree (stag)/ Deadwood/ Epicormic removal/ Formative prune/ Remove stakes/ Remove guards/ Remove Concrete or Asphalt/Remove tree/ Remove tree (retain logs)/ Stem injection/ Pest management/ Tree base maintenance required (mulch etc)/ Remove bee hive/ stump removal
Tree maintenance priority	**1** – Emergency (within 1 hr), **2** – 24hrs, **3** – 1 week, **4** – 1 month, **5** – 3 months, **6** – 12 months

OTHER FIELDS	Type of data to be entered
Comments	Free entry
Tree maintenance priority	Free entry
Inspected date	Free entry
Tree planted date (if known)	Date format xx/xx/xxxx
Root Barrier Installed	Yes/ No
Nomination for significant tree register	Yes/ No

WhichPlantWhere

Appendix 3:

Best practice guidelines

3.4 What tree growers need from you

https://whichplantwhere.com.au/resources

What tree growers need from you

By Gwilym Griffiths, December 10th 2021

Tree supply is a key component to any planting program, and understanding what growers need is essential to deliver successful tree planting programs. There are currently many planting initiatives and programs out there and securing the tree stock you need can be problematic. It requires good planning, communication and most importantly – time.

Growing trees can be a complicated process as there are many moving pieces and variables. Trees are a living product that have a shelf life, they are not static like a pallet of bricks which can sit as inventory for as long as needed. Growing trees requires careful management to ensure they meet the industry's needs. This can be described as the 'Grower's Jigsaw Puzzle', with numerous pieces needed to fit together to ensure successful tree supply can be achieved;

So, what do growers need from you to ensure you get the tree stock you want, when you need it. This can be simplified into two simple questions:

1. WHAT DO YOU WANT?
2. WHEN DO YOU WANT IT?

FIGURE 1: The growers' jigsaw puzzle - these pieces need to fit together to ensure successful tree supply can be achieved.

1. WHAT DO YOU WANT?

There are several elements to this question:

SPECIES
– what species of trees are you looking for? Species availability is often dependent on your timeframe. Growers can produce almost any species you want if you give them enough time to grow it. What growers produce vs what consumers want is often referred to as the 'chicken and egg syndrome' – who decides which species are grown, the market or the grower? The answer is both.

Large commercial growers look at what the market is demanding and adapt their stock lines to suit. This requires careful planning and use of data such as past sales history, analysis of the plant schedules they receive, predicting trends and staying in touch with the industry. They also generally carry regular lines of certain species that they know are in demand and perform well.

The more specialty growers tend stick to species they know are proven to perform and offer a range of trees to suit different scenarios and 'design niches' i.e. trees suitable for streets, parks, narrow verges, etc.

When planning your planting program, you should build flexibility into your species selection to allow for improved outcomes. The species itself is often not the primary concern, selecting the right tree for the right location is. Speak to the grower before you develop your planting list to see what they have available.

QUANTITY AND CONTAINER SIZE
– How many trees do you need and at what sizes? Depending on your lead times you may need to take what is available unless you allow enough time for the desired container size to be grown to order. Quantity and container size can be highly impacted by timing – if you allow enough time in your project you will generally be able to get what you need, the less time allowed in the program the more you will be at the whim of whatever is available in the nursery at that time.

FIGURE 2: Getting the container size you want can be highly impacted by timing. (Image credit: G.Griffiths)

QUALITY

– What is your specification for quality? You will need to tell the grower what you want in terms of the quality of your trees. This includes specifying if you want trees grown to AS2303 *Tree stock for landscape use* (which of course you do) but also specifying elements such as clear stem, trunk clearance, root ball depth and any other site-specific requirements you may need. Buying good quality stock is essential for the success of your planting programs. Trees are a structural asset that require structural integrity to perform. This integrity starts in the nursey and if the quality isn't right when planted, it will never be right.

Specify the standard – there is no need to go off and develop your own quality specification, this is what the standard is for.

"You either plant trees that have been grown to AS2303 or you don't plant at all."
Ross Clark

Timing can affect the quality of the stock you are receiving. Growing good quality trees takes time and expectations need to be stated up front. If you have left purchasing your trees to the last minute you are more likely to have to accept lesser quality trees. Unfortunately, not all growers apply the standard in the same way and so have varying levels of stock quality. If you are going through a large wholesaler who sources stock from throughout the country, they may have to purchase trees from growers with lower quality standards to fulfill your order – this is especially the case with last minute orders where the wholesaler doesn't have the stock you need in their own nursery.

Use a grower you trust, and preferably visit them to see how they implement quality standards. If your project requires certification of quality against the standard, tell the grower this at the time of ordering so they can ensure the correct auditing and processes are followed. Asking for certification at the end if you haven't specified it up front will lead to issues. You may also arrange an independent audit of the trees to ensure they meet the standard before you accept them for your project. Again this needs to be stated up front and allowed for in the program.

FIGURE 3: Tim Carroll from Andreasens Green discussing the importance of stock quality. *(Image credit: G.Griffiths)*

It is not good enough to simply specify the standard without checking compliance with it. The 'Tree Stock Standard Project', a collaboration between Hort Innovation, Nursery and Garden Industry Australia and Western Sydney University, developed a simple to follow non-destructive method of assessing tree stock against the standard. It considers a 'Preferred Percentile Range' for size index values that accounts for stem diameter, height and container size. This assessment method can be found here: https://www.westernsydney.edu.au/__data/assets/pdf_file/0011/1484282/HIE-card-A5.pdf

In some cases, selective destructive testing may be required to fully assess the quality of the tree's root system. Again, this needs to be stated up front and allowed for in the program as it will require additional trees to be grown.

FIGURE 4: Destructive testing can sometimes be the only way to check root quality *(Image credit: G.Griffiths)*

2. WHEN DO YOU WANT IT?

There are less elements to this question, it is however no less important. 'When do you want it' could almost be considered the most important question from a grower's point of view. Without a clearly defined timeline or insufficient lead time, many of the 'what do you want' factors such as quality, size and species can all be impacted. Lead time is everything when it comes to getting the trees you want at the quality you expect.

BEST PRACTICE – TREE SUPPLY CONTRACTS

Trees take time to grow and it is rare to find a grower that will have exactly what you want just sitting in the yard, especially for large planting projects. Best practice is to establish a 'forward growing contract', 'tree supply contract' or 'supply agreement' well in advance of when you need the trees.

Planning is key and locking in your plant supply should be one of the first steps in the process. Forward growing contracts ensure that you can get the exact tree species you want, at the quality you specify and at the exact time you need them.

It is also important to ensure that your lists are as complete and final as possible, as changes down the line can lead to additional costs and delays, especially with larger stock.

Get the site right. It is important to have assessed your planting site during your planning phase of the program. The location should not go on the planting list unless you know it can be planted in that location. Ordering trees based on an unverified list can cause headaches for both the grower and yourself with order cancellations, surplus stock and holding fees. Generally, a forward supply contract or supply agreement should include the following:

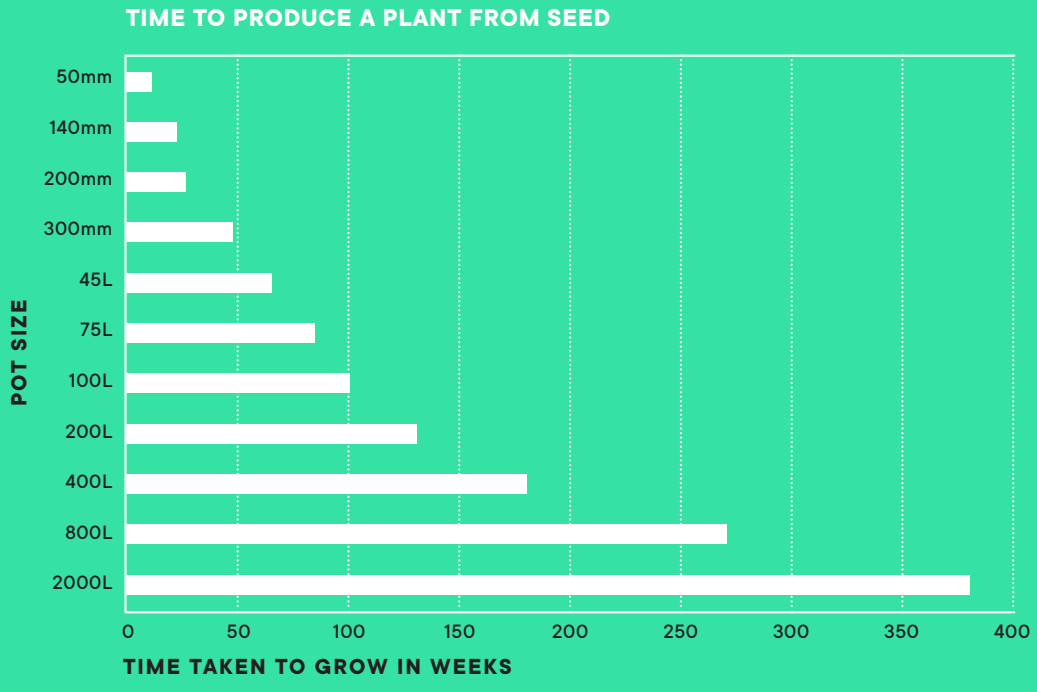
- Species and quantities (schedule)
- Container sizes
- Quality specifications and details of auditing (including hold points if required)
- Timeframe for delivery (within 2-3 months window) needs to be as specific as possible
- Details of any staged delivery requirements (for large planting programs that extend over several months)
- Agreement on $$ rates for holding or potting up if delays occur.

One way to achieve this forward procurement is to separate the supply and install parts of your contracts. This way you can arrange your supply well in advance of going to tender for the install part of the contract. You can novate the supply portion into the installation contract if required or simply specify that supply is by the client and allowances should be made in the quote for coordination of tree delivery.

Structure the contract to suit tree quality. Quite often it is easiest to specify one tree supplier to provide all your trees, but this may come at the cost of quality. Consider separating your tree supply to suit more specialty growers who can provide the quality of trees you require.

It is important to consider the length of time it takes to grow trees to a certain container size, for example; to grow a tree from seed to 45L can take 12 to 18 months. There are several variables such as species and climate, however as a guide, the table below outlines the length of time required to growth trees to certain container sizes;

FIGURE 5: The approximate time to produce a tree to different container sizes – based on fast growing species *(Image credit – Andreasens Green)*



WHEN BEST PRACTICE ISN'T POSSIBLE

It can be difficult to achieve forward procurement contracts for tree growing and sometimes circumstances just don't allow for it to happen. If this is the case the greater amount of lead time you can provide, the better.

"There is limited stock available in the market at any given time and it often comes down to a first in best dressed."

Tim Carroll Andreasens Green

It is quite common for contracts for tree planting projects to go out to tender as supply and install. Unless there are significant lead times built into the specification to allow for contract growing, the contractor will generally have to source plants within a very tight timeframe. If you cannot afford a long lead time you should be prepared to manage the following issues:

– You are more likely to have to accept poorer quality stock. Last minute orders are often sourced from other growers with lesser quality control. Availability becomes the priority rather than quality.

– Species substitutions are likely to occur. This is fine if you have built in the flexibility for this in your contracts.

- The container size you are looking for may not be available, which could then affect your installation rates and cause issues with other parts of your contact.

- Certain stock may not be available at the time you need it and this may cause delays to your planting program.

COMMUNICATION

Central to all elements of procuring trees is good communication. The more you can keep the growers in the loop with any changes to project timelines or design, the better. You may be able to avoid holding and potting up fees if you communicate these changes early enough. If they are regular stock lines for these growers they will generally be able to absorb the changes.

Timing is critical and understanding that trees are 'living products' that have a limited shelf life, they are not a pallet of bricks that have an indefinite shelf life, is very important. If there are time delays, which inevitably there often are, these delays need to be communicated effectively to all stakeholders within the project. If stock needs to be potted up there will need to be allowances made for additional costs and potential time delays while this stock grows into the next size category. In some cases, especially with lengthy delays, holding or potting up won't be an option and stock may need to sourced from another supplier or smaller container size batches of trees bought forward to fulfil your order. The grower's preference is to mitigate as much potting up/ holding as possible - they prefer to turn stock over.

ACKNOWLEDGEMENTS

We would like to acknowledge Ross Clark from Trees Impact Group and Tim Carrol from Andreasens Green for their contribution to this article.

Appendix 4:

Which Plant Where ‘What we heard’ document

Published 2017

What we heard: Species selection in urban spaces

Which Plant Where stakeholder engagement 2017

Plant selection decisions for urban spaces are complex and continually influenced by multiple factors depending who is making the selection. There were however consistent themes that arose in every workshop and the most common factors influencing species/plant selection for an urban space include:

▪ Professional experience

▪ Nursery stock availability

▪ Cost

▪ Ongoing maintenance considerations

▪ Site location and size - often competing against existing services/infrastructure (e.g. water, sewerage, power lines), the built environment and limited land availability

▪ Aesthetics such as “order” and/or “uniformity”

▪ Plant size, shape, form and purpose - windbreaks, shading, biodiversity, health and wellbeing, crime prevention

▪ Master plans of a local council

▪ Current trends and cultural values

Success and failures within urban spaces

Numerous successful urban spaces were identified in all major cities, most of which was attributed to correct species selection, well thought out planning, good site condition and preparation and ongoing maintenance regimes. Inversely, participants identified that if there is a disconnect between the design, construct and maintenance process, success of an urban green space is either limited or may lead to failure. There are various points at which failure becomes imminent:

§ Tender phase: cost of the initial design may be too expensive and selected plants are replaced with cheaper lower quality plants

§ Construction phase: removal of good quality top-soil, soil compaction, restricted growth space

§ Planting phase: availability of stock in nurseries, wrong soils used, species/plant substitution due to overspend on project

§ Maintenance phase: in the past, plantings were generally watered for the first year. This is now being extended to up to 3 years to ensure the plants survive.

It is important to note that the success or failure of an urban green space is not necessarily defined by whether a species survives or not, but rather if the right plant has been used for the context of the site. Many participants highlighted that a site could be deemed unsuccessful if the species selected does not provide multiple benefits. For example, shrubs planted along roads may be successful if measured by survival, but unsuccessful if success is measured in terms of providing enough shading for temperature mitigation.

Workshop participants also identified ongoing tensions that arise during this decision-making process, for example the competition between grey infrastructure and green infrastructure, the lack of professional knowledge during the construction phase and the difference between aesthetically pleasing species for the public versus council maintenance requirements. This too can have influence species selection and success of a site.

Collaboration and demonstration sites

All workshop participants agreed that demonstration sites provide an outstanding opportunity for collaboration and engagement, including trialling of different species to measure performance in the landscape. They are also an important part of public education. There should be a focus on the site, its use and its overall function. When asked to identify what would constitute a good demonstration site, the following were suggested:

- Street trees and urban forest
- Urban open space and parks
- Urban renewal sites
- New housing development sites
- Transport corridors, including roads, rail and nature strips
- Green roofs and walls
- Scientific complexity vs aesthetic
- Passive irrigation and water sensitive urban design

When asked if the project could use citizen science as a way of demonstrating success and failures, participants noted that some councils and bushcare groups are already undertaking these initiatives, and they were unsure whether additional citizen science data collection would support the project. To ensure that the focus of the project is relevant and useful, the use of a citizen science tool will be explored further and opportunities may exist to partner with existing sites.

Tools as resources

Part of the workshop was to discuss what tools and resources participants use for species selection in urban spaces. Some of the most common tools that were used include

- Google
- Websites such as PlantSelector+, iTree, Australian Plant Society (Australia), Specifying Trees
- Books, including international, national and local
- Local councils list
- Expert advice
- Nursery websites
- Local guides and fact sheets

Notably there was no one tool that everyone used for plant selection and more often than not tools and resources varied from state to state. This demonstrates the need for an online tool that can be used across Australia.

One of the final outputs of this project will be to create an interactive online tool that will guide species selection for urban plantings across Australia. The tool will build on research data obtained throughout the life of the project as well as incorporate the needs of the end-users.

All workshop participants identified that the end-users of this tool should be planners, practitioners and specifiers eg. local and state government, roads and maritime, landscape architects and developers and that the tool should be a decision-support system that enable users to focus on the important steps and questions to ask when prioritizing needs and desired outcomes of a particular space, including factors such as microclimate, urban context and ecosystem services, urban context (transport corridors, open space, housing development) and maintenance. Current tools that provide a good starting point for website development include PlantSelector+ and Citree.

Another key consideration is that the online tool needs to be dynamic and sustainable for the long-term and will need to develop a commercialise to ensure the longevity of the tool.

Team members will continue conversations with the Advisory Group, nursery and turf growers, practitioners and planners to ensure that the tool will be useable and relevant.

Appendix 5:

Which Plant Where presentations delivered throughout the project

Appendix 5: List of Which Plant Where presentations delivered throughout the project

Date	Location	Conference/webinar/presentation
21st-25th March 2017	Melbourne, VIC	Melbourne International Flower & Garden Show
11th-13th May 2017	Perth, WA	45th Annual Conference of the International Plant Propagator's Society
12th-14th July 2017	Melbourne, VIC	Ecocity World Summit
7th-8th September 2017	Adelaide, SA	18th National Tree Symposium
17th October 2017	Melbourne, VIC	Speciality Trees Beyond 40
3rd November 2017	Sydney, NSW	Hort. Frontiers Urban Greening Research Forum
6th December 2017	Melbourne, VIC	650 Council Forum – How is heat driving what and where to green?
2nd February 2018	Sydney, NSW	Clean Air and Urban Landscapes Workshop
19th February 2018	Hobart, Tas	Nursery Gardens Industry Conference
20th February 2018	Hobart, TAS	Hobart Growers Production Tour
5th June 2018		202020 Vision Green Light Tour
8th June 2018		Horizon Scanning Workshop on Future Urban Forests
8th August 2018	New Orleans, USA	Ecological Society of America conference
30th August 2018		Hortiman
6th September 2018	Adelaide, SA	TreeNET – Which urban trees can take the heat? Choosing trees for the future
1st November 2018	Melbourne, Vic	Three Days of Trees
26th November 2018	Brisbane, QLD	Ecological Society of Australia conference
11th February 2019	Canberra, ACT	Tree's for Canberra's future workshop
2nd May 2019	Sydney, NSW	NSW/ACT green infrastructure – focus on streetscapes presentation
4th May 2019	Hong Kong, CHN	Urban soil science for sustainable urban forests presentation
10th May 2019	Canberra, ACT	Tree week symposium
14th May 2019	Melbourne, VIC	Urban forests beyond boundaries
24th May 2019	Melbourne, VIC	Rethinking the urban forest
8th August 2019		202020 Vision growing together tour
13th November 2019	Melbourne, VIC	Two days of trees
25th November 2019	Launceston, TAS	Ecological Society of Australia conference
February 2020	Sydney, Newcastle, Perth, Adelaide	Which Plant Where 2020 National Roadshow
3rd – 5th March 2020		2020 Greenlife Industry Conference

19th May 2020	Online webinar	Embracing our successes and failures to create better urban green spaces
10th June 2020	Online webinar	Opportunity species for urban spaces
24th November 2020	Online webinar	How to monitor your urban forest for the future
22nd June 2021	Online webinar	The search for heat and drought-tolerant plants for urban places
24th November 2021	Online webinar	Grow them up right – how to successfully establish your new trees
November 2021	Online	Ecological Society of Australia conference
26th November 2021	Online webinar	What to plant where – cooling solutions for eastern suburbs homes
23rd February 2022	Online webinar	Greener ways to cool your home without costing the earth

Appendix 6:

Media coverage of the Which Plant Where project

Appendix 6: Highlights of media coverage of the Which Plant Where project

Media format	Date	Output/title
Article	29th January 2022	As Melbourne heats up, the cities trees are changing
Article	24th January 2022	In a hotter Sydney, some trees will thrive while others will wither
Article	14th January 2022	In blazing heat, some plants open leaf pores – and risk death
Article	11th January 2022	Without urgent action, these are the street trees unlikely to survive climate change
Radio	25th October 2021	How good are Australia's city greening programs?
Article	30th July 2021	Which tree is best for your small garden? It depends on where you live
Article	12th July 2021	Why lawn is secretly bad for your backyard
Article	28th January 2021	Revealed: the best trees for shading hot Sydney school yards
Article	25th January 2021	How to make your home more resilient to heatwaves and severe storms in summer
Article	19 October 2020	New research reveals the hidden danger of sweltering heat in Western Sydney schools
Article	26th September 2020	The importance of urban trees
Article	21st September 2020	Accidental heroes: how the world's cities can help save the trees
Article	20th August 2020	Finding the most adaptable urban trees for a changing climate
Article	17th August 2020	How adaptable are common urban tree species under drought conditions?
Article	29th June 2020	Australia: NSW government announces guide for greener spaces policy
Article	19th May 2020	Covid 19 'pulse check': the results are in (you might be surprised)
Article	25th February 2020	Trees! What are they good for? Absolutely everything!
Article	13th February 2020	Warning over 'heat island' effect over cities as tree coverage declines
TV	16th December 2019	Changing times with Dr Josh Byrne, Prof David Ellsworth and Assoc Prof Linda Beaumont
Radio	31st July 2019	Dr Alessandro Ossola interviews on ABC Radio National
Article	26th July 2019	Cities need more trees, but which ones will survive climate change?
Article	26th July 2019	Our cities need more trees, but some commonly planted ones won't survive climate change
Article	16th July 2019	Our sustainable future starts today
Article	5th July 2019	Hedging against climate change
Article	24th June 2019	Are cities planting the right trees – not just for the present, but for the future?
Podcast	20th May 2019	Leigh Staas gives an update on the Which Plant Where project
Article	March 2019	Gardening Australia magazine: plants of the future (Appendix 6)
Radio	28th March 2019	Gwilym Griffiths and Leigh Staas discuss the effects of climate change on urban trees
Article	29th January 2019	'Living Lab' in Sydney's Inner West helps researchers understand plant selection for urban spaces in a changing world
Article	21st September 2018	The plants that will survive in a changing climate
Video	31st July 2018	Professor Linda Beaumont was interviewed for Hort. Frontiers
Radio	30th March 2018	Radio interview on green cities with Dr Renee Prokopavicius

Video	23rd March 2018	Meet the researchers behind Where Should All The Trees Go? and Which Plant Where?
Video	1st October 2017	Which Plant Where? Species selection for urban greening
Article	4th September 2017	Which Plant Where?
Article	2nd June 2017	Crowd-sourced national plan launched to increase Australia's urban green spaces by 20 per cent

Appendix 7:

Summary of outputs from the Which Plant Where project

Appendix 7: Summary of Which Plant Where outputs

Output	Description	Detail
Which Plant Where project factsheet	Document which provides a brief overview about the Which Plant Where project and its different modules.	Uploaded onto the Which Plant Where website to be freely downloaded by the public.
Nursery paper August 2017	Publication highlighting the scope of the Which Plant Where project and implications for the nursery industry.	Published on the Nursery & Garden Industry Australia website (Greenlife Industry Australia)
Living Labs brochure	Fact sheet introducing the Which Plant Where Living Labs to prospective participants.	Uploaded onto the Which Plant Where website to be freely downloaded by the public.
Cooling benefit of urban trees factsheet	Fact sheet highlighting the cooling benefits afforded by urban trees	Uploaded onto the Which Plant Where website to be freely downloaded by the public.
Identifying drought-tolerant plant species	Factsheet on the drought-tolerant plant species that are expected to thrive under future climate change. A total of 54 plant species were classified as either drought-tolerant, moderately drought-tolerant, or drought-avoiding	Made available on the Which Plant Where website
Environmental sustainability of horticultural plants fact sheet	Fact sheet reporting on the results of the heat and drought experiments conducted for Module 3 of the Which Plant Where project	Distributed as part of the Which Plant Where webinar entitled 'Opportunity Species', attended by 50 people.
How we calculated planting co-benefits in Which Plant Where	Technical guide describing how co-benefit scores were calculated for constructed palettes on the Which Plant Where tool.	Available freely to download from 'The Science' page on the Which Plant Where webtool.
How we calculated canopy cover in Which Plant Where	Technical guide describing how maximum tree canopy cover was calculated at the palette-level on the Which Plant Where tool.	Available freely to download from 'The Science' page on the Which Plant Where webtool.
How we estimated the climatic suitability for each species, at postcode-level	Technical guide describing climate suitabilities were calculated for each postcode on the Which Plant Where tool.	Available freely to download from 'The Science' page on the Which Plant Where webtool.

How we measured drought and heat tolerance in Which Plant Where	Technical guide describing how heat and drought tolerance rankings were created for the Which Plant Where tool.	Available freely to download from 'The Science' page on the Which Plant Where webtool.
How we calculated planting diversity in Which Plant Where	Technical guide describing how planting diversity was calculated for each palette on the Which Plant Where tool.	Available freely to download from 'The Science' page on the Which Plant Where webtool.
What is a weed and how are they identified in Which Plant Where	Technical guide defining weeds and how they were classified in the Which Plant Where tool.	Available freely to download from 'The Science' page on the Which Plant Where webtool.
Climate-ready street tree trials: a best practice guideline	Best practice guide detailing how to plan, design and implement a scientifically rigorous trial of street tree species in an urban context.	Presented at the Treenet National Tree Symposium in September 2020. Also available freely to download from 'The Science' page on the Which Plant Where webtool.
How to successfully establish your new trees	Best practice guide describing step by step how to successfully plant trees in an urban context.	Available freely to download from 'The Science' page on the Which Plant Where webtool.
How to measure your urban forest: a best practice guide to establishing a tree inventory	Best practice guide outlining how to implement a tree inventory for urban forests.	Available freely to download from 'The Science' page on the Which Plant Where webtool.
What growers need from you	Best practice guide highlighting what information growers need to deliver successful tree planting programs.	Available freely to download from 'The Science' page on the Which Plant Where webtool.

Appendix 8:

Which Plant Where project factsheet

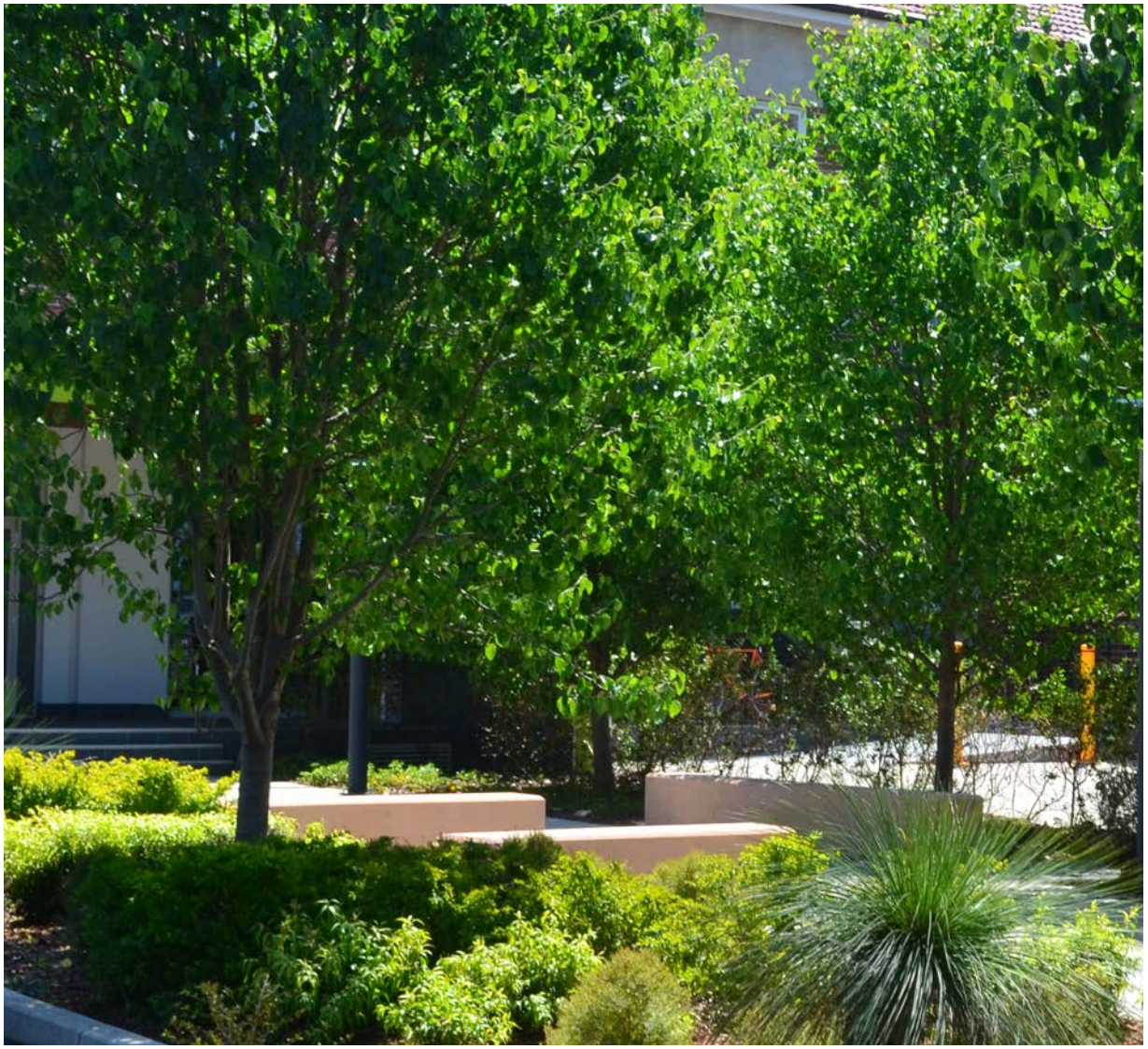
Published June 2017

WHICH PLANT WHERE?

Facilitating urban green space

Which Plant Where is about selecting the right plants for the right urban space with an eye on the future.

WHICH PLANT WHERE?



Hort Innovation

MACQUARIE University

WESTERN SYDNEY UNIVERSITY

Hawkesbury Institute for the Environment

NSW GOVERNMENT Office of Environment & Heritage

www.whichplantwhere.com.au

THRIVING URBAN GREEN SPACES

More greenery in our towns and cities is imperative for healthy minds, healthy bodies and a healthy environment. A key challenge for greening Australia's urban environments is to ensure that future plantings are made with trees, shrubs and turf that can tolerate the climate conditions that will occur in the near future.

The Which Plant Where program is a five-year research program that will investigate how well current landscaping species will cope under the more extreme climates that Australia's cities will face and investigate opportunities for new species and varieties for the urban context.

The idea of the Which Plant Where project was developed through the 202020Vision national Growing the Seeds tour in 2015. It is being funded via the Hort Frontiers Green Cities Fund, a strategic partnership initiative developed by Hort Innovation that addresses the biggest challenges facing the future of Australian horticulture. Having the confidence that tomorrow's urban plants will survive and thrive in a changing world is crucial for the long-term viability of our industries and for creating a climate-resilient urban landscape.

To ensure that our research and tools are relevant to end-users, the WPW project held five interactive workshops across Australia, bringing together a diverse group of stakeholders including nursery and turf growers, practitioners, developers, landscape planners and designers, as well as state and local government representatives. These workshops attracted over 110 people from 86 organisations. The project will continue to work with all stakeholders over the life of the project.

202020™ VISION 20% MORE GREEN SPACES IN URBAN AREAS BY 2020

MODULE 1

Species Attributes And Climatic Tolerance

The first module will focus on fifty plant species identified in the project's Target Species List, and will develop maps that demonstrate each species' suitability to both current and future climates across Australia.

These maps will be used to demonstrate how well or poorly a particular species will be able to tolerate future conditions in urban centres across Australia as the climate changes, based on our current understanding of species' climatic requirements.

Our research might demonstrate, for example, that a particular species of tree is already at the very limit of its ability to cope with heat, and that the only suitable place to plant this species in the future will be in cool-climate or more temperate locations. This kind of information would be very useful to a council seeking to avoid investing in tree species for street planting that are unlikely to cope with higher temperatures.

We will also use information from national herbaria and other sources to quantify each species' climatic limits - the warmest, coldest, driest or wettest conditions they can cope with. This information will then be tested through the Planting Successes and Failures module of the research programme to ensure that the Interactive Plant Features Tool matches the right plant in the right region with an eye on the future.

We will also be working with growers, nurseries, landscape architects and many others to capture their recordings of major plant traits including:

- growth rate and form
- height
- canopy density
- ground cover
- longevity
- seasonality
- water quality
- allergenicity
- air and water quality influences and urban temperatures
- insect resistance
- ornamental and amenity features
- and biodiversity impacts.

MODULE 2

Successes And Failures

There are many factors that contribute to the success or failure of urban plantings. These factors form the basis for the second module of the Which Plant Where research programme:

- Climate factors from broad scale temperature and rainfall patterns, to urban heat effects, and local microclimate that determine the ability of plants to survive and thrive.

- The environmental conditions to which those species are exposed during establishment (such as soil depth, quality, nutrients, water availability, exposure), as well as pathogen, insect and weed loads, that affect plant survival, performance and health.

By working with stakeholders across the plant supply chain, we can obtain a wide range of data on the factors that make or break a successful urban planting. This way, we can learn from what has previously worked and avoid the factors that clearly contribute to reduced planting success, or even failure, in the urban context.

How Will We Achieve This?

- By identifying partners, such as councils, that are willing to share data and results of historic plantings across a range of urban settings. This will help us to evaluate success rates in relation to environmental and species selection decisions.

- By selecting a range of target locations where we can conduct much more detailed and longer-term monitoring of the sites, with consideration of climatic conditions, soil attributes, watering regime, fertiliser use and the presence of pathogens.

- By establishing new test-planting sites where we plant a range of species and monitor their performance under contrasting climatic and soil attributes. Here, we are particularly interested in species that are only just coping with current temperatures and rainfall regimes to assess how they respond to more challenging climatic conditions.

We are also interested in the additional benefits that urban greening brings to our cities and towns, such as greater numbers of birds, insects and other wildlife, cleaner air and cooler temperatures at street level, and associated benefits to human health and well-being.

MODULE 3

Heat And Drought-Tolerant Species That Will Thrive

Some plants can cope with adverse weather conditions better than others, and it is important to understand just how much heat and drought stress each of our target species could potentially tolerate.

Using both glasshouse and field trial sites, we will be subjecting our target species to some of the toughest conditions they are likely to face over the coming century, including:

- Lengthy or intense heatwaves, along with
- Extensive drought periods or periods of drought followed by intense rainfall
- High average temperatures at unusual times of the season

This regime will help us understand the abilities of different plants to cope when they are exposed to more than one climate stressor simultaneously. Watering is clearly a crucial element of a plant's success, and so we will test different watering regimes combined with different soil types and media to obtain information on a plant's water use efficiency and drought tolerance. In the real-world, plants can be affected by multiple factors at once so it is important for us to impose a combination of conditions that are 'realistic but tough' so that we can see how the plants really respond.

A Sound Research Process Is Critical

One of the most important factors in any research process is to ensure that the results are based on credible, trusted, best-practice research so that stakeholders can be confident that their decisions are based on the most up-to-date information available.

That's why all of our research has to adequately account for realistic climate change, carbon dioxide, heat and temperature, and drought predictions combined with feasible production and management processes for trees and other plants. We will achieve this by working with growers and our partners where possible, and applying the very best established methods of designing research for repeatability, credibility and accuracy.

MODULE 4

Interactive Plant Features Tool

The interactive database will use the data collected in Modules 1, 2 and 3 to build a national tool that helps to select plants against a range of filters. Previously-developed tools provide a good number of options to select plants for purpose, colour, flowering, height or availability, but there are none that are backed by extensive testing of plants under current and future climatic conditions.

The Interactive Plant Features Tool aims to offer a large range of filters that include not just plant features but also factors such as safety, amenity value, location and co-benefits. This comprehensive tool will provide guidance and the understanding needed for successful urban plantings across Australia's urban environment now and into the future.

Major planned features of the Interactive Plant Features Tool include:

- Maps that show the changes in climate suitability for plants under predicted climate change scenarios
- Filters that reflect common urban planting needs, such as rooftops, verges, water-sensitive design, parks or urban forests.

Value-added characteristics may include heat mitigation, wildlife and biodiversity benefits, pollinator-friendliness or tolerance to urban constraints such as footpaths.

The expected release date of the Interactive Plant Features Tool is 2021.

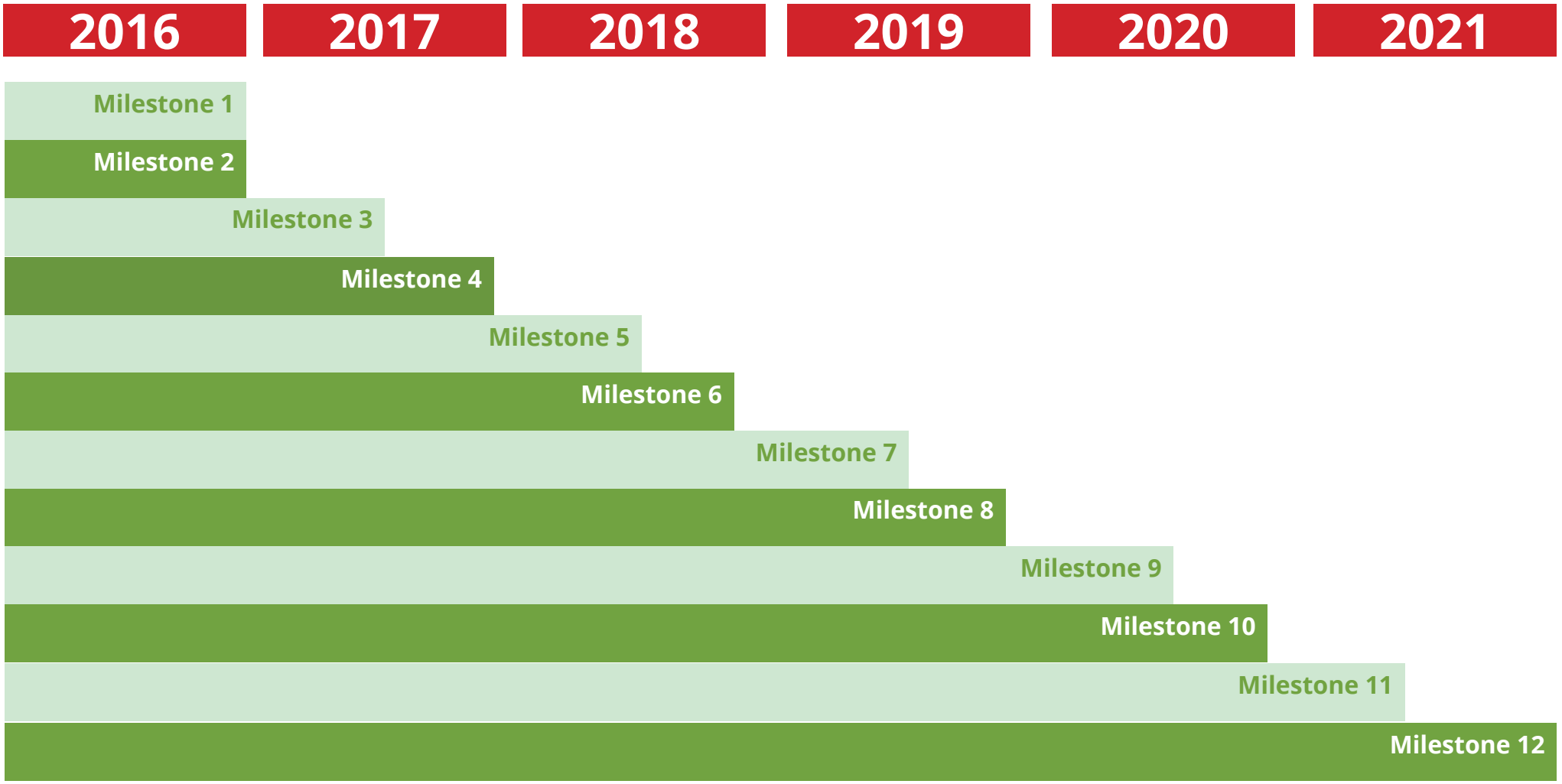
Best-Practice Technical Design Guide

Supporting the Interactive Plant Features Tool will be a technical design guide that bases its recommendations for urban plantings on the best research and industry knowledge available.

MAJOR DELIVERABLES

MILESTONE	CRITERIA
Milestone 1 & 2	Stakeholder engagement, form advisory group, identify possible demonstration sites.
Milestone 3	Finalise species list, identify success/failure planting sites.
Milestone 4	Standardised screening protocol, establish growth trial sites.
Milestone 5	Finalise species trait database and bioclimatic tolerance data.
Milestone 6	Expand growth trials with nurseries.
Milestone 7	Finalise maps of species distributions. Develop co-benefit assessments at 5 sites.
Milestone 8	Develop factsheets of co-benefits of urban planting.
Milestone 9	Complete bio-monitoring site data collection. Finalise climate screening of 50 species, develop factsheets for 25 species.
Milestone 10	Module 2 Hold workshop on biomonitoring outcomes. Module 3 Conduct final stakeholder workshop on screening, finalisation of commercialisation plan. Module 4 Beta version of online tool.
Milestone 11	Module 2 Scientific Paper on success/failure of plantings. Module 4 Completion and launch of online tool, conduct final stakeholder workshop.
Milestone 12	Final reporting.

PROJECT TIMELINE



RESEARCHER PROFILES

Professor Michelle Leishman is the Chief Investigator for the Which Plant Where? research program based at Macquarie University.

Professor Leishman has a wealth of experience and expertise in climate change impacts on plants across a wide range of contexts and the fundamental effects of rising temperatures and carbon dioxide on native and managed ecosystems.

In this research program, Professor Leishman is responsible for:

- overall research and program leadership and management
- supervision of researchers, postdoctoral fellows and students
- establishing rigorous processes to ensure high-quality research
- review of publications, reports and project outputs
- leadership of stakeholder communication, engagement and feedback processes

Professor David Ellsworth is the Chief Investigator for the research program at Western Sydney University's Hawkesbury Institute for the Environment.

Professor Ellsworth brings an incredible wealth of expertise on the impacts from elevated carbon dioxide in plants, and is currently the Lead Scientist at the EucFACE experiment.

Under the Which Plant Where? project, Professor Ellsworth brings leadership and management capabilities to drive the direction of the research and trials at WSU. He will be primarily responsible for:

- Management and leadership of the overall research program
- supervision of researchers, postdoctoral fellows and students
- review and editorial of publications, reports and guidelines
- facilitation of research meetings and committees
- stakeholder engagement, feedback and communication

RESEARCHER PROFILES

Dr Linda Beaumont is a Chief Investigator on the research program's module 'Species attributes and climatic tolerance'.

Linda has an extensive track record of research, teaching and public outreach at Macquarie University, bringing to this project a wealth of expertise on understanding and reducing uncertainty in species distribution modelling and biological responses to climate change.

Under the Which Plant Where? research program, Linda's primary responsibilities include:

- coordination of Module 1 Species Attributes and Climatic Tolerance
- integration of the results from Module 1, in particular results from the research on species traits and modelling
- supervision of researchers, postdoctoral fellows and students
- project management, communications and outreach efforts.

Dr Rachael Gallagher is a Principle Advisor of the Which Plant Where? program based at Macquarie University. Rachael is an ecologist specialising in the functional biogeography of the Australian flora. She combines location data from digitised herbarium specimens (which describe the spatial occurrence of Australia's ~20,000 native plant species) with information on their functional traits to map and analyse patterns of plant function in the Australian landscape.

As part of the Which Plant Where? research project, Rachael's responsibilities include:

- Advising on the development of the trait database
- editorial and review of the research reports, publication and outputs
- industry and research engagement
- co-supervision of students and coordination of researchers

RESEARCHER PROFILES

Professor Lesley Hughes is a Chief Investigator on the Which Plant Where? research program based at Macquarie University.

Lesley has extensive experience and expertise in the impacts that a changing climate places on plants and ecosystems, and brings to the project well-established industry, research and governmental links that will strengthen the engagement of the project.

Lesley's responsibilities include:

- supervision and coordination of researchers, postdoctoral fellows and students
- writing and editorial of reports, publications and other outputs
- Expertise on experimental and research design protocols
- Contribution to communications and outreach efforts

Dr Muhammad Masood is a Technical Officer based at Macquarie University, responsible for the operation of glasshouse and growth room facilities.

Muhammad's major responsibilities under the Which Plant Where? program include:

- management of Macquarie University's plant growth facilities
- support for researchers and experiments
- researcher training for use of facilities
- maintenance and installation of equipment used by the researchers at the growth facilities

RESEARCHER PROFILES

Associate Professor Sally Power is a Chief Investigator for the Which Plant Where? research program based at the Hawkesbury Institute for the Environment at Western Sydney University and explores drought sensitivity assessments of the target species.

Sally's research explores how human activities affect processes at the leaf, plant and community level, and how these effects influence ecosystem function and sustainability.

In the Which Plant Where? project, Sally's primary responsibilities include:

- drought sensitivity assessments of the target species
- evaluation of the field research on impacts of climate and soils on planting successes
- contribution to the design, implementation and operations of experiments and their analysis and publication
- co-supervision of students
- community, industry and research engagement and outreach

Dr Paul Rymer is a Chief Investigator for the Which Plant Where? research program based at the Hawkesbury Institute for the Environment at Western Sydney University with specialist expertise in the ability of plants to adapt to changing environmental conditions by exploiting their genetic and phenotypic traits.

Through the Which Plant Where? program, Paul is responsible for delivery of the Successes and Failures Module. Paul's responsibilities include:

- planning and implementation of the module and its research design
- engagement with stakeholders from industry and research to build on their data and experiences as to what has succeeded and what has failed
- research that links plant growth and survival to environmental factors such as soil and climate
- 'picking the winners' from stress-testing research on plants to highlight the factors that make plants resilient

RESEARCHER PROFILES

Professor Ian Anderson is a Chief Investigator on the Which Plant Where? program and Director of the Hawkesbury Institute for the Environment at Western Sydney University. Ian specialises in the relationships between soil microbes and plants that acts as a major contributor to planting success in many Australian soils.

In the Which Plant Where? program, Ian's role is for overall strategic direction and management of the research team at Western Sydney University, and co-supervision of students.

Professor Mark Tjoelker is a Chief Investigator for the Which Plant Where? research program based at the Hawkesbury Institute for the Environment at Western Sydney University.

In the Which Plant Where? program, Mark is responsible for advisory and research design on soils and pot size factors, co-supervision of students and industry engagement particularly in connection with other Horticulture Innovation Australia projects.

RESEARCHER PROFILES

Leigh Staas is the Project Manager for the Which Plant Where? program, handling overall project management, coordination of meetings and workshops, budgets, planning and engagement.

Leigh has an extensive background in project management for research and manages other environmental and scientific research programs underway at Macquarie University.

Within this project, Leigh's major responsibilities include:

- project management including planning, implementation and tracking of the program to meet milestones and stay within budget
- organisation of the stakeholder and steering committee meetings and workshops
- reporting to committees and Horticulture Innovation Australia
- development and implementation of communications plans including internal and public outreach, stakeholder engagement and to committees.

Dr Nisha Rakhesh is the Research Development Advisor for projects in association with Horticulture Innovation Australia, including the Which Plant Where? project.

Based at Hawkesbury Institute for the Environment at Western Sydney University, Nisha excels at forging connections through research with partners across industry and academia.

RESEARCHER PROFILES

David Thompson is a research engagement and communications specialist based at the Hawkesbury Institute for the Environment at Western Sydney University.

Under the Which Plant Where? research program, David contributed to the initial communications design process and supports the team in delivering public, academic and industry communication and outreach.

ADVISORY GROUP

Hamish Mitchell
Managing Director
Speciality Trees (VIC)

Hamish Mitchell is the owner and Managing Director of Speciality Trees.

With a passion for trees in urban environments & a career that spans nearly 30 years in amenity horticulture, plant management & development, production and plant marketing, he is a knowledgable resource in all areas of tree selection and consultation.

Tim Carroll
Councils & Key Account Manager
Andreasens Green Wholesale Nurseries (NSW)

Recognised as the company's advanced tree specialist, Tim oversees supply of trees to most of the major developers in Sydney as well as councils for their street tree planting programs.

Tim conducts the training of all nursery staff in AS2303, quality control and also lead groups of landscape architects, councils and tree planters in similar training.

Tim also attends workshops of organisations such as AILA and the Local Government Landscape Design Forum.

Leanne Fleming
Research and Innovation Manager
Fleming's Nurseries (VIC)

Leanne holds a science degree and postgraduate horticulture qualifications, and has more than 23 years experience in the industry and has a range of experience in:

- propagation
- bare root
- containerised tree production
- street tree installation and maintenance
- event and project management
- management of quarantine processes (domestic and international)
- broad overview of the nursery industry on state, national and international levels

ADVISORY GROUP

Dr Lyndal Plant
Lyndal Plant Urban Forester Pty Ltd (QLD)

Lyndal's 25 years of local government urban forest management experience, research and engagement skills has helped align organisational goals with contemporary evidence gathering techniques to suit projects, policy development/review and cutting edge initiatives.

Lyndal sees the forest, not just the trees – helps plan and monitor for outcomes, not just the outputs – focuses on trees for people ("human habitat" values) - and engages customers and partners.

Some of Lyndal's urban greening achievements include:

- Brisbane Neighbourhood Shadeway program, including av. 10,000 shade tree plantings per year for cooling shade-hungry pathways, playgrounds and carparks.
- Project reporting for Brisbane's 2 million tree project
- Development and monitoring of native street tree species trials.
- Brisbane's Subtropical Boulevard Vision and delivery strategy.
- Member of expert panel for review of Canberra's Urban Forest Renewal Strategy

Most recently Lyndal has published on evidence gathering methodologies for urban greening target evaluation and property value/tax based business case for investment in leafier streetscapes.

Carole Fudge
Sales and Marketing Manager
Benara Nurseries (WA)

Carole has been involved in the nursery industry for 40 years, 30 years of this at Benara Nurseries in sales and marketing.

Carole has been involved in the scheduling and research of plant varieties, of which they grow over 1500 different species.

During this time Carole has worked with Landscape Architects, landscape contractors, local government and retailers working out which plants would work best in their particular projects.

Carole has extensive experience in what works in the landscape in Western Australia, both native and exotic, and also works with breeders trialing new plant material for both landscape and retail markets.

ADVISORY GROUP

Hugo Struss
General Manager and Director
Tinamba Turf (QLD)

Hugo has been working on the family business since finishing primary school. Between boarding school and work at home on the main property, Tinamba Turf (the family business) has continued to grow into what is now the largest family owned turf production business in Australia. After finishing school Hugo worked on the property while studying commerce (majoring in marketing) and then to construction management. At this time he also competed heavily at an elite level in national and international rowing.

In 2010, Hugo joined the business full time in a sales role, and worked his way up to general manager. He oversees the sales, operations on and off farm, staff, business development and production of three farm sites. Tinamba Turf has nearly 1000 acres under irrigation.

Lara Solyma
Senior Environmental Planner
City of Gold Coast (QLD)

After completing an environmental science and management degree, Lara worked for 10 years as a practitioner of horticulture, landscape design, plant design, landscape construction, landscape maintenance and ecological restoration within southeast Queensland; developed her plant knowledge and a passion for the plants and vegetation communities of south-east Queensland, and started and successfully operated her own horticultural business. Lara started working in local government in 2006 and over eleven years has worked in a variety of roles across the organisation, further developing skills and expanding knowledge and abilities into new areas, including:

- Public open space design and assessment, including streetscaping
- Public landscape works approvals. How to facilitate improved, extensive street tree plantings
- Species selection and issues of biodiversity, soils, urban constraints, provenance, nursery availability, lack of plant knowledge, specification of plant species and palette diversity
- Project management, including the Gold Coast Regional Botanic Gardens which included design and plant selection for a proposed Children's Garden and extensive wetland / stormwater treatment system
- Vegetation asset management, vegetation cover and use of i-Tree Canopy
- Environmental planning, policy development and policy implementation, community consultation, significant tree registers.

ADVISORY GROUP

Simon Adermann
Business Manager
Lawn Solutions Australia (QLD)

Simon has been involved in the turf industry for 37 years, commencing with an apprenticeship in Turf & Greenkeeping in 1981 and 13 years as a Greenkeeper in the lawn bowling industry. From there, Simon commenced employment with Nuturf, a specialist product supply company to the turf industry as the QLD manager and in 2007 took the position of National Sales Manager managing the responsibility of the Australian and overseas business. After 18 years with Nuturf he was made National Business Manager for Lawn Solutions Australia in 2013. Simon now manages 43 turf production farm accounts nationally.

Carl Heyne
General Manager
Heyne Nurseries (SA)

Tim Sansom
General Manager
Australian Ecosystems (VIC)

Tim has extensive horticultural and business skills, working his way through several roles over the last 13 years with The Diggers Club. During this time he worked as a Garden and Site Manager at the prestigious Garden of St Erth in Central Victoria curating an internationally acclaimed public garden and through various horticultural business management roles (including 10 years' intimate involvement with nursery operations).

Tim has recently taken a role as General Manager - Nursery, with Australian Ecosystems, a company that specialises in seed collection, propagation and sourcing of local provenance plants for all Victorian regions. In this role, he is involved with the production and marketing of plants for clients including Commercial and Residential developers, Civil Contractors, Landscape Architects, Local Councils and State and Federal Government Departments.

ADVISORY GROUP

David Callow
Team Leader
Urban Forest & Ecology Urban Sustainability
City of Melbourne (VIC)

David has two decades of experience in Landscape Horticulture. He has qualifications within the fields of Horticulture, Arboriculture and Natural Resource Management.

David is passionate about creating healthy and diverse urban forests through community participation, strategic thinking and continuous improvement.

In his role at the City of Melbourne, he is responsible for implementing the Urban Forest Strategy, through the annual tree planting program.

Prior to joining the City of Melbourne, he was self-employed as an Arboricultural and Landscape Consultant.

Brigid Adams
Manager IWM Program Governance and Capacity Building
Department of Environment, Land, Water & Planning

Brigid is a highly personable multi-skilled Environmental Engineer with 16 years' experience in water management and climate change mitigation.

She possesses well-developed strategic planning and project management skills, with proven technical expertise.

Brigid is experienced in all aspects of the project delivery life cycle, from strategy development to program implementation, monitoring and evaluation.

Her influential interpersonal skills allow for effective communication with team members and key stakeholders to achieve organisational goals in an effective manner.

ADVISORY GROUP

Mathew Plummer
Managing Director
EvergreenConnect (QLD)

Mathew is a horticulturalist with 30 years' experience in the nursery industry, having worked in a range of wholesale nurseries growing everything from plugs to ex-ground production stock.

As operations manager of Newton Container Trees in Brisbane in the 1990's, Mathew took a leading role in Queensland to critically look at and bring new production methods into the industry regarding tree root development.

As well as a number of horticultural qualifications, Mathew has undertaken business studies including a Diploma of Business Management and a Masters of Business Administration which has allowed him to successfully manage nursery businesses and create his own business from scratch, EvergreenConnect. EvergreenConnect is being positioned to be a vital communication and data link for all facets of the horticultural industry.

Suzanne Dunford
Principal Project Officer
Impacts and Adaptation
Office of Environment and Heritage (NSW)

Suzanne Dunford is the Principal Project Officer in the Impacts and Adaptation Team at the NSW Office of Environment and Heritage. Her role focuses on supporting local government with tools, information and capacity to minimise the impacts of climate change in their local communities, through the establishment of projects including: the $1 million Building Resilience to Climate Change grants program, the NSW Urban Green Cover program, and leading an Integrated Regional Vulnerability Assessment of as part of the Towards a Resilient Sydney project.

This four year project engaged with over 270 different local and state government decision makers, and leading researchers to identify the impacts of climate change on social, economic and biophysical systems in Metropolitan Sydney and opportunities to respond. It was delivered in partnership with the Department of Planning and Environment, the Sydney Coastal Councils Group and the Western Sydney Regional Organisation of Councils.

Suzanne has have been working in the climate change field in a range of communications, program and policy roles since 1998. She has a Bachelor's degree in Organisational Communication from Charles Sturt University and a Masters of Public Administration from the University of Sydney.

ADVISORY GROUP

Noel Corkery
Managing Director
Corkery Consulting (NSW)

Noel is a Registered Landscape Architect with more than 30 years of landscape and urban design consulting experience throughout Australia and Asia. Noel has managed multi-disciplinary consultant teams for projects involving 'green infrastructure' such as public open space, urban development, landfills, forestry, highways, windfarms and mines. Noel has developed a strong understanding of sustainable development principles and their application to integrated planning and design.

Noel's qualifications:

- Bachelor of Science (Forestry), 1968, Australian National University.
- Master of Landscape Architecture, 1978, Cornell University.
- Master of Business Administration, 1989, Australian Graduate School of Management (UNSW).
- Master of Cross-Disciplinary Art & Design, 2011, COFA, UNSW.

Noel was awarded the AILA 2013 NSW Presidents Award in recognition of outstanding contribution to the profession of landscape architecture.

Jason Hick
Director, Principal Consultant
Emerge Associates (WA)

Jason is an environmental consultant and now part-owner of a combined environmental consultancy and landscape architectural practice, the largest of its kind in Western Australia.

Emerge Associates works across many projects for property developers, local government and state government, and integrate the provision of a range of technical environmental advisory areas with landscape architectural design and delivery.

WHICH PLANT WHERE?

For more information:

Leigh Staas
Project Manager - Which Plant Where Research Project

Email: leigh.staas@mq.edu.au
Telephone: 02 9850 6297

www.whichplantwhere.com.au

Which Plant Where is funded by the Hort Frontiers Green Cities Fund, part of the Hort Frontiers strategic partnership initiative developed by Hort Innovation, with co-investment from Macquarie University, Western Sydney University and the NSW Office of Environment and Heritage and contributions from the Australian Government.

Appendix 9:

Nursery Papers
(August 2017)

Nursery & Garden
Industry Australia

WHICH PLANT WHERE?

A key challenge for greening Australia's urban environments is to ensure that plantings are made with trees, shrubs and turf that will survive and thrive for many decades to come.

This Nursery Paper outlines the aims of a five-year research project which brings together a consortium of research and industry partners to investigate the suitability of various plant species under current and future climate scenarios and in various urban areas, from street plantings to housing developments and open spaces.

Summary

- The *Which Plant Where* project will develop an interactive online tool containing information about which species of plants and turf will thrive in urban spaces under particular soil, water, aspect and climatic conditions, in specific geographical areas.
- It will include available information on whether a plant attracts native fauna or mitigates heat or air pollution, is a potential allergen risk, or is likely to drop limbs.
- This project draws on input from diverse stakeholders including nursery and turf growers, developers, landscape planners and designers, and state and local government representatives.

BACKGROUND

The idea of the *Which Plant Where* project emerged from the 202020 Vision Growing the Seeds national tour in 2015, where there were consistent calls for a tool that could be used to select plants, backed by evidence and data on climate, species, position and other features.

The *Which Plant Where* research program aims to test the performance of major and new urban landscape species with scientific validity and accuracy under new and more extreme urban conditions.

The project is the first of its kind, and will culminate in an online interactive tool that will map the distribution of suitable habitats for various plant species across urban areas of Australia.

To ensure the research and tools will be relevant to end-users, the initial stages of the project included five interactive workshops across Australia which attracted more than 110 participants from 86 organisations.

PHOTO: Denys Nevozhai.

Nursery & Garden Industry Australia

This communication has been funded by Hort Innovation using the nursery research and development levy and contributions from the Australian Government.

Hort Innovation Strategic levy investment | NURSERY FUND

THE PROJECT

The *Which Plant Where* project is a collaboration between Macquarie University, Western Sydney University and the New South Wales Office of Environment and Heritage, as part of the Green Cities Fund, a strategic partnership initiative of Hort Innovation.

Although the project is not directly funded by the nursery industry levy, growers are an integral part of this project and six growers are members of the project's Advisory Group.

The aims of the project are to:

- provide guidelines to councils, planners, residents, landscapers and horticulturalists about what to plant
- support local councils' climate adaptation programs
- mitigate risks associated with poor plant selection
- inform better local labelling of plants at a consumer level.

The online interactive tool will be designed for use by a wide range of stakeholders, from nursery and turf growers to developers, landscape planners and designers, councils, and individuals.

Western Sydney University is hosting some of the trials for Which Plant Where, growing key target plants in climate controlled glasshouses to see how well they tolerate urban heatwaves, and to seek even better horticultural varieties to withstand them. PHOTO: David Thompson.

THE RESEARCH

There are four modules of research that form the basis of *Which Plant Where*.

SPECIES ATTRIBUTES AND CLIMATIC TOLERANCE

The first module will focus on 100 plant species identified in the project's Target Species List, and will develop maps that demonstrate each species' suitability to both current and future climates across Australia.

These maps will be used to demonstrate how well or poorly a particular species will be able to tolerate future conditions in urban centres across Australia as the climate changes, based on current understanding of species' climatic requirements.

The project will use information from national herbaria and other sources to quantify each species' climatic limits – the warmest, coldest, driest or wettest conditions they can cope with.

Researchers will also be working with growers, nurseries and landscape architects to capture their recordings of major plant traits including:

- growth rate and form
- height
- canopy density
- ground cover
- longevity
- seasonality
- water-use efficiency
- insect resistance
- allergenicity
- biodiversity benefits.

GREEN CITIES

The Green Cities Fund encourages co-investment in research to inform nursery industry business decisions and customer advice, and its aim is to invest in strategic, longer term research which drives a measurable increase in urban green space.

The *Which Plant Where* project comes under the Green Cities Fund's climatic and environmental theme, which targets research that will develop tools and knowledge to assist Australia to overcome its current and future climatic and environmental challenges, such as extreme weather patterns and the urban heat island effect.

It has three key objectives:

- To increase understanding of the current climatic and environmental barriers to expanding urban green space
- To increase understanding of the role that urban greening plays in mitigating the effects of climatic and environmental change
- To develop the tools and resources which will lead to increased application of urban greening in design.

FACTORS THAT CONTRIBUTE TO THE SUCCESS OR FAILURE OF URBAN PLANTINGS

These include the conditions to which species are exposed during their early establishment phase, such as soil quality, nutrient supply, watering and heat stress, that might affect their early survival; and long-term climate factors such as urban heat effects, drought stress or insect or fungal damage, or subsequent groundworks that might damage plant roots.

By working with stakeholders across all links throughout the plant supply chain, the project can obtain a wide range of data on the factors that make or break a successful urban planting.

The project will identify partners, such as councils, that are willing to share data and results of historic plantings across a range of urban settings.

A range of target locations will be selected for much more detailed and longer-term monitoring of sites, with consideration of climatic conditions, soil attributes, watering regime, fertiliser use and the presence of pathogens.

New test-planting sites will be established where the performance of a range of species will be monitored under contrasting climatic and soil attributes, to assess how they respond to more challenging climatic conditions.

There will also be investigation of the additional benefits that urban greening brings, such as greater numbers of birds, insects and other wildlife, cleaner air and cooler temperatures at street level, and associated benefits to human health and well-being.

HEAT AND DROUGHT-TOLERANT SPECIES THAT WILL THRIVE

Some plants can cope with adverse weather conditions better than others, and it is important to understand just how much heat and drought stress each of the project's 100 target species could potentially tolerate.

Using both glasshouse and field trial sites, they will be subjected to some of the toughest conditions they are likely to face over the coming century, including lengthy or intense heatwaves; extensive drought periods or periods of drought followed by intense rainfall; and high average temperatures at unusual times of the season.

This regime will assist understanding of the abilities of different plants to cope when they are exposed to more than one climate stressor simultaneously. Watering is clearly a crucial element of a plant's success, so different watering regimes combined with different soil types and media will be tested to reveal a plant's water use efficiency and drought limits.

In real-world situations, plants can be affected by multiple factors at once so it is important to impose a combination of conditions that is 'realistic but tough' to see how the plants really respond.

INTERACTIVE PLANT FEATURES TOOL

The interactive database will use the data collected in previous modules to build a national tool that helps to select plants against a range of filters.

Previously-developed tools provide a good number of options to select plants for purpose, colour, flowering, height or availability, but there are none that are backed by extensive testing of plants under current and future climatic conditions.

The Interactive Plant Features Tool aims to offer a large range of filters that include not just plant features but also factors such as safety, amenity value, location and co-benefits.

The Interactive Plant Features Tool will contain:

- maps that show the changes in climate suitability for plants under predicted climate change scenarios
- filters that reflect common urban planting needs, such as rooftops, verges, water-sensitive design, parks or urban forests
- value-added characteristics that may include heat mitigation, wildlife and biodiversity benefits, pollinator-friendliness or tolerance to urban constraints such as footpaths.

The expected release date of the Interactive Plant Features Tool is 2021.

To ensure that the research will be relevant to end-users, the initial stages of the Which Plant Where project included interactive workshops across Australia which attracted more than 110 participants from 86 organisations. PHOTO: David Thompson.

NEXT STEPS

The project sets out a number of milestones to be delivered over the five years from 2017 to 2021.

An Advisory Group has been formed, stakeholders advised and engaged, and identification of potential demonstration and field testing sites is underway.

By 2018 it is anticipated that a species list will be finalised, a standardised screening protocol established, and success/failure planting sites and growth trial sites established.

It is anticipated that the final version of the Plant Features Tool will be launched in 2021, although streamlined versions may be available sooner.

A national best practice technical design guide will also be developed as part of the project, to demonstrate best-practice case studies of species selections around Australia.

IMPLICATIONS FOR THE NURSERY INDUSTRY

Confidence that tomorrow's urban plants will survive and thrive is crucial for the long-term viability of the nursery industry, and this project will assist the industry to identify future-proof native and exotic species for enhancing urban greening.

The *Which Plant Where* research will deliver a host of outputs including new research on plant water efficiency and heat stress, case-study demonstration sites and a website which makes it easier to select plant species across the country based on future climate predictions.

The *Which Plant Where, When And Why Database For Growing Urban Greenspace* (GC15002) has been funded by Hort Innovation with co-investment from Macquarie University, Western Sydney University and the New South Wales Office of Environment and Heritage.

PHOTO: Chris Barbalis.

The project will provide an Interactive Plant Features Tool that nurseries can use to inform their own production and share with customers along the supply chain, to ensure plantings in urban spaces are sustainable, resilient, attractive and durable under the toughest of climates.

Growers have a key role to play in better understanding which, where and how urban plants can best provide health, wellbeing and liveability outcomes both now and in the future, if the industry is to meet the goal of increasing urban green space by 20% by 2020.

LINKS TO RESOURCES

Which *Plant Where project*: *www.whichplantwhere.com.au*

Hort Innovation project page: Which Plant Where Project: *http://horticulture.com.au/co-investment-project/gc15002*

Hawkesbury Institute for the Environment, Western Sydney University: *https://www.westernsydney.edu.au/hie/research/research_projects/green_cities_which_plant_where*

Centre for Smart Green Cities, Macquarie University: *http://www.mq.edu.au/research/research-centres-groups-and-facilities/secure-planet/centres/centre-for-green-cities/our-projects*

Green Cities Fund: *http://horticulture.com.au/co-investment-fund/green-cities-fund*

PAST EDITIONS OF NURSERY PAPERS ARE AVAILABLE ONLINE on the Nursery & Garden Industry Australia website *http://www.ngia.com.au/Section?Action=View&Section_id=46*

Appendix 10:

Screening protocol for seeking climate-hardy horticultural species and varieties in the WPW project

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Screening Protocol for seeking climate-hardy horticultural species and varieties in the WPW project

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Summary

We describe a protocol for ranking and selecting heat- and drought-tolerance of horticultural species based on growth in a common environment and an experimental heat-wave and/or drought using state-of-art glasshouses and instrumentation. Heat tolerance is measured and ranked on the basis of the critical temperature for chloroplast integrity. Drought tolerance is surveyed and ranked on the basis of the turgor loss point of leaves, equating to the plant wilting point. Both of these measures provide a quantitative basis for ranking species for tolerance of adverse climatic conditions, which allows us to identify vulnerabilities of current horticultural stock as well as opportunities to find climate-hardy horticultural species and discover new potential stock for future urban plantings.

Background

We have devised glasshouse experiment to address the aims of Module 3 ('Survive and Thrive') in the Which Plant Where project: to characterise the susceptibility and resilience to drought and heat waves in 50 to 100 target plant species/varieties, which achieves Milestones for the project (principally MS 104, 105, 106, and 109) and feeds physiological information into Module 1 of the project and to the overall project database underlying the web tool.

Here we lay out an experimental design that will allow us to quantify and rank Australian native and exotic horticultural species according to their physiological heat and drought tolerances, which have previously not been quantified. The glasshouse experiment is distributed over two different glasshouse sites, with half of the total plant species/varieties designated for growth in glasshouses at the Hawkesbury Institute for the Environment (HIE, Richmond, Australia) and the other half to be grown at Macquarie University glasshouses (MQ, North Ryde, Australia). A subset of 5 species will be common to both glasshouse facilities to test the null hypothesis that the major response variables we test are not sensitive to the location of the study, cultural practices nor minor environment differences that may occur during the study period.

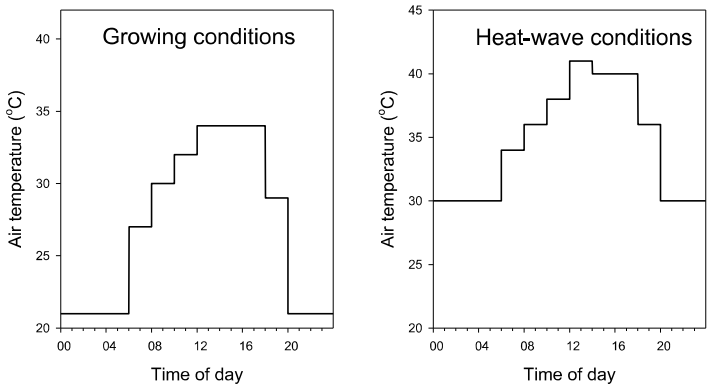
We sourced plants from nurseries within their native range, with known provenance when possible. Most plants are sourced as tubestock or 1.8-L (140 mm) pot size, but larger plants (4.5-L pot size; 200 mm) will be used if smaller sizes are unavailable. Plants are bare-rooted and then transplanted into 6-L pots (18 cm square by 24 cm high). The 6-L pots contain native potting mix (<30% sand/coir, >70% screened composted pine bark; Australian Growing Solutions, Tyabb, VIC) and 6.7 g/L of controlled-release native plant fertiliser (Scotts Australia Osmocote Slow Release). They are grown for at least two months to ensure plants develop under uniform conditions before starting screening measurements. This reduces the chance that cultural practices in the source nurseries would cause unexplained variation and confound scientific results.

We selected horticultural stock covering a range of plant families, a mixture of growth form targeting 50% trees, 25% shrubs, and 25% climbers, herbs and grasses. We selected 80% native Australian species and 20% exotic species for inclusion in the studies based on industry input. In addition, we ensured that 40% of the horticultural species and varieties were derived from a list of top-selling stock for eastern Australia and sourced the remainder as 'opportunity' species amongst those judged relatively uncommon based on nursery holdings of the last 5 years indexed by EvergreenConnect (EvergreenConnect, Sunnybank, QLD). All the native species/varieties originated across all of the major climate zones of Australia, excluding cold-temperate species. We also ensured that the horticultural stock had desirable horticultural traits, such as glossy green leaves, strappy leaves, coloured foliage, ornamental flowers, weeping habit, and/or a dense-foliage growth form.

Growth regime

The two sets of glasshouses will be maintained at an average temperature of 27 °C, with a diurnal range from 21 to 34 °C and the maximum temperature spanning six hours at midday (12:00–18:00; Fig. 1). These conditions were chosen to represent warm, summer urban conditions that could occur in the major cities around Australia, but are not excessive or stressful temperatures for the plant species in this study.

Fig. 1 Growing conditions (left panel) and heat wave conditions (right panel) for the glasshouse experiments.



Drought

Plants will be well-watered for about 2 months after establishment. At that point a gradual drought treatment will be imposed using the method described by Snow and Tingey (1985), as modified by Fernández and Reynolds (2000) (see Fig. 2). This method allows a uniform and repeatable soil water potential in pots (Wookey *et al.* 1991; Saulescu *et al.* 1995), regardless of plant size, by the establishment of a combined matric and gravitational potential gradient (Fig. 2). Soil drying can be applied gradually using this approach to more closely simulate natural drought events in the field. Pots will be placed into plastic containers on top of a block of commercial floral foam (Fig. 2), which will be soaked overnight as recommended by the manufacturer, and kept hydrated. Based on a pilot study, we will choose water levels to obtain two treatments (well-watered control (WC) versus water-withheld (WD)). A set of control plants (n=5 plants per species) will be maintained using one of two methods: (1) partially filling containers until the water level is 1 cm below the base of the pots (dimension z, Fig. 2) or (2) daily watering by drip irrigation, which is necessary to prevent space limitation in the glasshouse. All control pots will be maintained at the same volumetric water content (VWC at field capacity ~33%). Droughted plants (n=5 plants per species) will be exposed to a gradual drought by increasing z over a one-month drought period (before measurements). The level of drought we obtain with this technique will be quantified by measuring water content (VWC; Hydro-sense II, Campbell Scientific, Thuringowa, QLD) and predawn leaf water potentials (PMS Instruments, Corvallis, OR). Whilst drought tolerance will differ among our study species, our target is to surpass permanent wilting point (VWC=10%) for the most susceptible species. The drought treatment is randomly allocated to individual plants a priori.

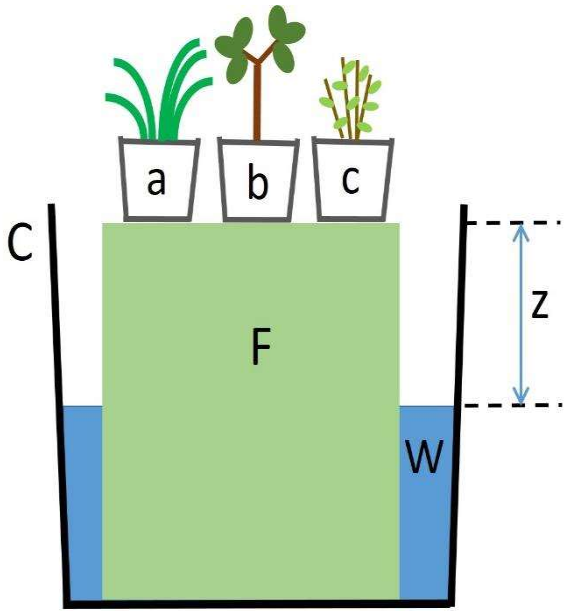


Fig. 2 Diagram of the drought-imposition method, where *C* plastic container, *F* floral foam, *W* water, *a,b,c* pots with nylon mesh at the bottom and filled with potting mix, and *z* water-table depth Figure adapted from Fernández and Reynolds (2000).

Heat-wave

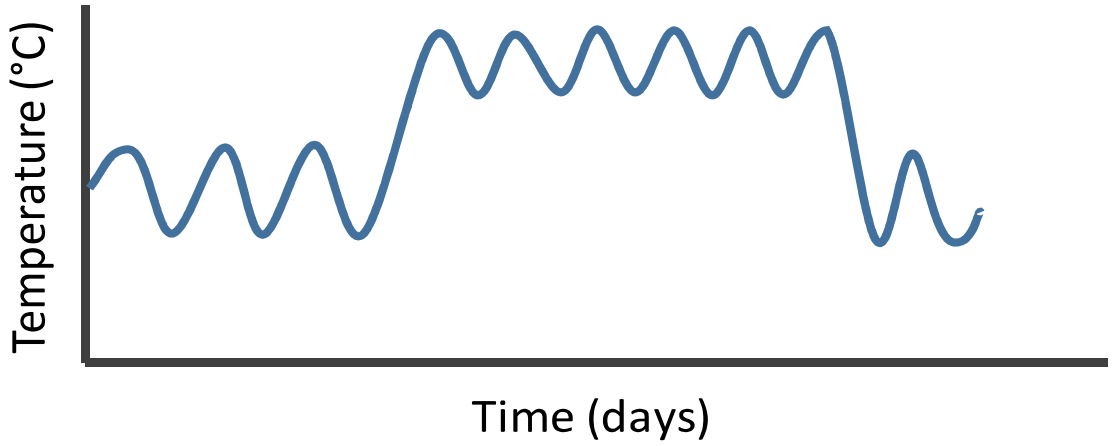
After a standardization period, we will expose plants to a 6-day heat-wave in the glasshouse (Figs. 1 and 3), designed to test how our study species cope with heat stress alone and drought combined with heat stress. Heat-waves are known to have severe negative impacts on a number of organisms, particularly in cities (Karl et al. 2009). The World Meteorological Organization (WMO) defines a heat-wave as: "A period during which the daily maximum temperature exceeds for more than five consecutive days the maximum normal temperature by 5°C". For our purposes, we have selected a 6-day duration to provide an even number of days for evaluating the response to heat-waves. We have deliberately designed the heat-wave as an abrupt increase in temperature, rather than a ramp or build-up, as we are designing a separate set of experiments to evaluate pre-treating plants to increase hardiness to heat-waves (Diana Backes' Ph.D. work). This design allows plants to be measured on different days but

after the same number of high-degree hours (HDH, the number of hours that temperatures were above an arbitrary threshold level of heat-treatment).

For heat-waves, pots will be moved into another glasshouse at an average temperature of 35 °C (on average 8 °C warmer than the acclimation temperature; Fig. 1), with a diurnal range of 11 °C, and the maximum temperature spanning six hours at midday (12:00–18:00) as has been observed during heat waves for western Sydney. Air humidity will remain high in the heatwave to minimise confounding effects of vapour pressure deficit with heat (Amthor et al. 2010), though it is impossible to entirely disentangle the two effects. We will conduct a number of core screening measurements throughout the study (see below).

Recovery

Fig. 3 Diagram depicting the temperature regime during a 6-day experimental heat-wave imposed in the glasshouse, showing diurnal fluctuations in temperature (see Fig. 1 for exact conditions).



After the heat wave, plants will be kept well-watered in the glasshouse for a period of 2-4 weeks and monitored visually to determine the degree of whole-plant recovery from heat and drought stress.

Core Measurements

Dark-adapted chlorophyll fluorescence

Considering the photosynthetic machinery in plant leaves, photosystem II (PSII) in the thylakoid membrane of chloroplasts is considered the most vulnerable to heat stress (Havaux *et al.* 1991; Georgieva & Yordanov 1994). Chlorophyll fluorescence provides a mechanism for dissipating excess light energy from leaves (Maxwell & Johnson 2000) and is commonly used to quantify the status and damage of the photosynthetic apparatus during stress events. Increased fluorescence at high temperatures is caused by a disruption of electron transport and formation of damaging oxygen radicals (Schreiber & Armond 1978; Bukhov *et al.* 1990; Yamane *et al.* 2000). The maximum quantum yield of PSII (F_v/F_m) reflects the health of the photosynthetic apparatus and has been widely used as a stress indicator (Murchie & Lawson 2013). A dark-adapted F_v/F_m ratio is near ~0.8 in non-stressed conditions across many plant species (Björkman & Demmig 1987; Maxwell & Johnson 2000; Murchie & Lawson 2013), as it is closely related to the maximum efficiency of light utilisation for photochemistry. This value varies depending on species and leaf absorptance properties (see Ellsworth, HIE Technical Report, "Chlorophyll fluorescence as a tool for assessing plant heat and drought tolerance"). Lower dark-adapted F_v/F_m values than those demonstrated by unstressed plants

can indicate deactivation of PSII by photo-oxidation or the induction of sustained quenching (Demmig-Adams & Adams 2006; Murchie & Lawson 2013). This photo-damage to PSII reaction centres is most prevalent in response to stress, when photosynthesis is greatly reduced and the photochemical system for utilizing internal reductant is also diminished (Bilger *et al.* 1984; Larcher 2000).

We will use F_v/F_m as a key measure of plant photosynthetic response to stress events, namely heat-stress, for urban plants and planting stock. The F_v/F_m parameter has been successfully used to screen wheat cultivars that have high heat tolerance (Sharma *et al.* 2015). After dark-adapting leaves for 30 min, F_v/F_m can be rapidly measured by applying a saturating pulse at an intensity of 8000 µmol m^{-2} s^{-1} for 0.8 s using a pulse-amplitude modulated fluorometer (MINI-PAM-II/B, Heinz Walz GmbH, Effeltrich, Germany). We have already made such measurements for horticultural varieties. We will measure dark-adapted F_v/F_m in all species/varieties before, during, and after the heat-wave. These fluorescence parameters were optimized during a feasibility study at HIE in July 2017 (see Ellsworth, HIE Technical Report, "Chlorophyll fluorescence as a tool for assessing plant heat and drought tolerance") and were shown to be sensitive indicators of plant tolerance of heat-waves.

Critical temperature for chloroplast function

We will measure the temperature-dependent increase in fluorescence (F_o–T curve; Fig. 4) of attached, dark-adapted leaves using the method in Bilger *et al.* (1984) described by Knight and Ackerly (2002). Briefly, single leaves will be placed on top of the ceramic surface of a Peltier thermoelectric heater (Marlow Industries, Dallas, TX USA). Steady-state fluorescence (F_o) of leaves will be measured in vivo using a pulse-amplitude modulated fluorometer (MINI-PAM-II/B, Heinz Walz GmbH, Effeltrich, Germany) as leaf temperature (T) is increased from 30 to 60 °C at a rate of 1 °C per minute. The resulting F_o–T curves are species-specific, and **the critical temperature (T_{crit}, see Fig. 3) will be used as the primary measure to rank plant species according to their photosynthetic thermal tolerance** (Schreiber & Berry 1977; Knight & Ackerly 2002) and has also been used to characterize the thermal safety margin of plants from different biogeographical regions and climates (O'Sullivan *et al.* 2016). The T_{crit} marks the temperature where chlorophyll *a* fluorescence rises rapidly and PSII is disrupted (Bilger *et al.* 1984). It is calculated as the intersection of two linear relationships, the slow-rise phase and the fast-rise phase, of the F_o–T curve (Fig. 4).

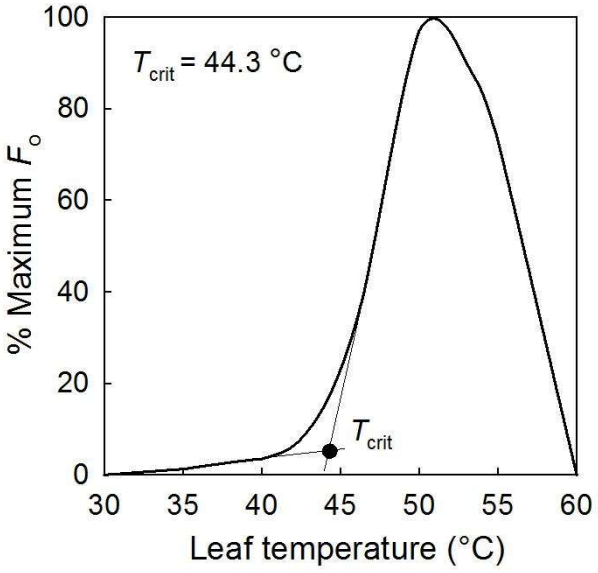


Fig. 4 An example of an F_o–T curve with T_{crit} indicated; adapted from Knight & Ackerly (2002).

We propose to use the F_o–T curves to rank all species in the glasshouse experiment by their T_{crit}. These measurements will be conducted on n = 5 individuals of all species in both glasshouses. So, the primary heat tolerance measure will comprise one fully mature leaf per each of 5 plants subjected to the measurement cycle in Fig. 4. In addition, for a subset of plant

species, we will measure F_o–T curves during the experimental heat-wave (see above) to determine how variable T_{crit} is over time. There is evidence for diurnal and seasonal fluctuation of T_{crit} (Valladares & Pearcy 1997; Braun *et al.* 2002), but our expectation is that T_{crit} represents the basic membrane fatty-acid composition and will not show much acclimation (O'Sullivan *et al.* 2016).

Osmotic potential

Leaf water potential (Ψ_{leaf}) at the turgor loss point (π_{tlp}), or wilting point, is a species-specific parameter that is strongly related to plant drought tolerance (Engelbrecht *et al.* 2000; Baltzer *et al.* 2008). It is correlated with water availability within and across biomes (Bartlett *et al.* 2012b), as well as a number of drought tolerance traits among species, including Ψ_{leaf} at 50% loss of stomatal conductance, Ψ_{leaf} at 50% loss of hydraulic conductivity, and Ψ_{leaf} at plant death (Bartlett *et al.* 2016). The π_{tlp} metric has also been shown to effectively rank species according to the stringency with which stomata regulate plant water status during drought (Meinzer *et al.* 2017). **We will use π_{tlp} (Fig. 5) to rank species according to their leaf-level drought tolerance, because it serves as a proxy for more complex traits that govern whole-plant response to drought.** These measurements will be taken during the 3 weeks prior to initiating drought, on fully-mature leaves, with 3-5 replicates per species.

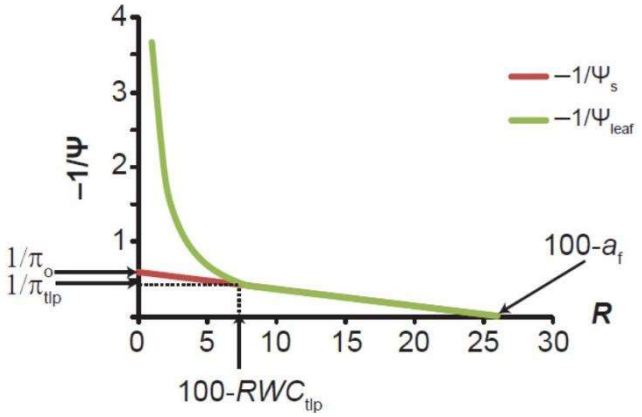


Fig. 5 A pressure–volume curve; the relationship between inverse leaf water potential vs. relative water content of a leaf. The π_{tlp} and π_o are indicated. Figure from Bartlett *et al.* (2012b).

The π_{tlp} is mainly driven by the leaf osmotic potential at full turgor (π_o, (Bartlett *et al.* 2012b)). A pressure–volume curve (Fig. 5), which measures the decline of leaf water potential during dehydration, can be used to estimate π_{tlp} and π_o (Koide *et al.* 1989). We will measure pressure–volume curves on a subset of species using the standard method described by Sack *et al.* (2010). The standard pressure–volume curve method is too time-consuming for a large species set, however. Instead, the π_o can be easily measured using the method described by Bartlett *et al.* (2012a). Briefly, leaves are excised from the plant and rehydrated for three hours (Arndt *et al.* 2015), before 40-mm diameter leaf pieces are cut and frozen in liquid nitrogen for 2 min. Leaf discs are then thawed for 10 min, punctured 50–75 times with sharp-tipped forceps, and π_o is monitored on a dewpoint psychrometer (WP4C, Decagon Devices, Pullman, WA, USA) until equilibrium has been achieved, i.e. there is <0.01 MPa change in π_o over 2 min. There is a close linear relationship between π_{tlp} and π_o (Bartlett *et al.* 2012a) that we will use to estimate π_{tlp} for all study species.

Supporting ecophysiological measurements/traits

Indicator of water-use efficiency

The long-term water-use efficiency of plant leaves can be measured using the carbon isotope ratios ($\delta^{13}C$) when leaves are grown under similar atmospheric humidities and carbon dioxide concentrations (Farquhar & Richards 1984), as we will have in the glasshouse. Leaf $\delta^{13}C$ provides a time-integrated measure of the ratio of leaf internal to external CO_2 (c_i/c_a) over the leaf lifespan and is mediated by variation in stomatal and mesophyll conductance with respect to the carbon assimilation rate (Farquhar *et al.* 1989; Ehleringer 1991). Leaf $\delta^{13}C$ has been used to accurately indicate water-use efficiency in crops (Farquhar & Richards 1984; Adiredjo *et al.* 2014).

Leaves (n=3 leaves per plant for each of 3 plants) will be collected, bulked and oven-dried at 70 °C to a constant mass, and ground to a fine powder. The $\delta^{13}C$ will be measured using an elemental analyzer coupled to a gas isotope mass spectrometer. Values of $\delta^{13}C$ will be calculated according to standard δ notation: $\delta = \left(R_{\text{sample}}/R_{\text{standard}} - 1\right)1000$ ‰, where R is the ratio of the heavier isotope (^{13}C) to the lighter isotope (^{12}C). The standard is traceable to belemnite carbonate from the Pee Dee formation, South Carolina, USA. Our analyses for $\delta^{13}C$ will be done at the University of Western Australia (The West Australian Biogeochemistry Centre), or at the University of California. Measurements at both labs will be comparable as they're traceable to the same standard, but we will also analyse our own internal standard as a check.

Leaf thickness and LMA

Leaf dry mass per unit area (LMA) is a key species morphological trait, as it increases with increasing leaf lifespan and is related to photosynthetic rate, transpiration rate, and nitrogen concentration (John *et al.* 2017). Leaves with higher LMA have either (1) higher leaf tissue density or (2) thicker leaves (Poorter *et al.* 2009). Plant species in dry environments generally have higher LMA than mesic environments (Poorter *et al.* 2009). To determine LMA, we will measure leaf area (n=3 leaves per plant; same as above for $\delta^{13}C$) using a leaf area meter and leaf dry mass after oven-drying at 60 °C to a constant mass. Leaf thickness will be estimated as the product of (LMA × LWC), where LWC is the ratio of saturated fresh mass to leaf dry mass (Vile *et al.* 2005). We will independently validate this method by measuring leaf thickness at three locations along the leaf lamina of one leaf per plant using digital calipers.

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Appendix 11:

Which Plant Where Living Lab

Published June 2018

Which Plant Where Living Lab

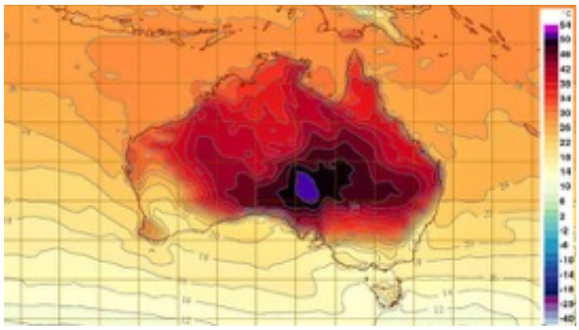
Summary

This factsheet introduces the Which Plant Where Living Lab, a new network of urban planting sites as part of the Which Plant Where research program, funded by Hort Innovation Australia. The Living Lab involves the establishment and monitoring of new urban planting sites to evaluate plant performance across a wide range of environmental conditions and the associated environmental benefits that underpin healthy urban environments.

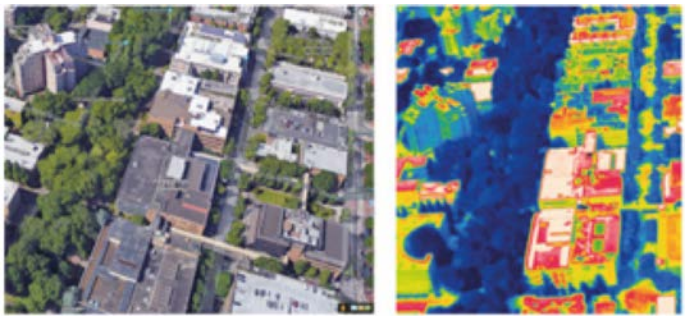
We invite your organization to become part of the network of Living Labs to help inform future urban planting strategies at the local, regional and national scale.

The urban climate

Man-made surfaces absorb and re-radiate heat very effectively, meaning that cities are typically hotter than surrounding areas – the so-called urban heat island effect. Set against a background of increasingly warmer and more extreme climates across the globe, urban populations are experiencing ever more challenging climatic conditions. The ability of plants to provide shade and cool the local environment makes urban greening an effective strategy for improving the liveability of our cities, particularly in a changing climate.



In recent years, meteorologists have added a new colour to our weather maps to indicate the record-breaking, intense heat experienced during heatwave conditions.



Thermal images of cities highlight the temperature differences between buildings and adjacent vegetation, and the essential role that urban vegetation plays in reducing heat at the local scale.

In addition to the cooling effects of vegetation in urban environments, trees and shrubs provide a myriad of other benefits to society. For example, they make major contributions to improving air quality and regulating water cycling by trapping air pollutants and reducing storm water run-off. Furthermore, by providing habitat to support biodiversity in our city-scapes, urban vegetation contributes to human wellbeing and the health of urban ecosystems across Australia.

One of the key challenges in landscape design is to identify which plant species will thrive in urban landscapes and provide the greatest benefits for urban populations. The *Living Lab* will help increase our understanding of the role of local environmental conditions (e.g. planting context, micro-climate, soil type) in determining plant performance and the benefits associated with urban greening.

Which Plant Where Living Lab

What is the *Which Plant Where Living Lab*?

The *Living Lab* is a standardised set of tree and shrub plantings suitable for significant urban areas throughout Australia that will allow us to: 1) test the performance of species with different morphologies and growth forms under a wide range of environmental conditions; and 2) evaluate the co-benefits of urban greening (e.g. heat mitigation, enhanced biodiversity) by examining the role of vegetation structure and diversity.

There are three levels of participation in the *Living Lab*, involving trees and shrubs, planted on their own and together:

Level 1: Tree only design (4 tree species)

Suitable for:
-Streetscapes
-Medians
-Paths
-Parks

Level 2: Shrub only design (4 shrub species)

Suitable for:
-Streetscapes
-Medians
-Road verges
-Below power lines
-Above underground utilities

Level 3: Trees + shrub design (4 tree plus 4 shrub species)

Suitable for:
-Parks
-Gardens
-Larger plantings

Example of linear plantings for the three levels of participation. Non-linear planting designs are also appropriate.

Please note that a minimum of four sets (of 4 tree species and/or 16 shrubs) per level is needed for those level plantings you include at your site.

The *Living Lab* design will allow us to assess the benefits of greater species diversity and structural complexity of plantings across urban landscapes. By establishing a network of *Living Labs* in cities across Australia, we will be able to compare the performance of, and benefits associated with, standardised tree and shrub plantings in a variety of different climates, soils and landscape contexts. It will also allow us to evaluate the extent to which more structurally complex plantings (trees + shrubs) that provide a more diverse habitat, can support greater diversity. Other potential benefits we will study include the role of different leaf and canopy characteristics in the ability of plants to intercept particulate matter from the air and thus reduce urban pollution. Also, the cooling potential of different canopy structures, to explore the role of vegetation in mitigating the urban heat island effect.

Which Plant Where Living Lab

Our Species

As part of a target list of several hundred species being tested under *the Which Plant Where research program*, we have identified several important test species that allow a robust comparison among tree species with different life histories (deciduous *vs*. evergreen) and shrub species with different plant architectures and flower characteristics.

Trees

1) Lagerstroemia indica
(exotic/deciduous/8 m)

2) *Liriodendron tulipifera*
(exotic/deciduous/20 m)

3) *Elaeocarpus reticulatus*
(native/evergreen/15 m)

4) *Lophostemon confertus*
(native/evergreen/20 m)

Shrubs

1) Melaleuca citrina
(native, 3 m)

2) *Westringia fruticosa*
(native, 1.5 m)

3) *Baeckea virgata*
(native, 1.5 m)

4) *Melaleuca thymifolia*
(native, 1 m)

Although we have a list of preferred tree and shrub species, we have an extended list of species that can be substituted/added in to the different categories, if required. Please contact us for more details.

How can you get involved?

1. It's quite simple. Depending on the size and characteristics of your available urban space, first decide whether you are able to plant both trees and shrubs, or just trees or shrubs on their own. Remember that we need you to plant a minimum of four sets of each planting level. For level 1 (trees only) that's 16 trees; for Level 2 (shrubs only) that's 64 shrubs and; for Level 3 (trees + shrubs) that's a total of 16 trees plus 64 shrubs.

2. Let's get to work! We can help you to acquire good quality plant material and will provide a standardized, easy-to-follow planting protocol.

3. Finally, we will monitor plant performance in all network planting sites, and provide you with tailored, site-specific and network-level information relating to growth, survival and co-benefits during the project.

For more information

Please contact Dr Manuel Esperon (m.esperon-rodriguez@westernsydney.edu.au), Dr Paul Rymer (p.rymer@westernsydney.edu.au), Prof. Sally Power (s.power@westernsydney.edu.au) or Leigh Staas (leigh.staas@mq.edu.au).

Which Plant Where is funded by the Hort Frontiers Green Cities Fund, part of the Hort Frontiers strategic partnership initiative developed by Hort Innovation, with co-investment from Macquarie University, Western Sydney University and the NSW Office of Environment and Heritage and contributions from the Australian Government.

Appendix 12:

Plants of the Future

Gardening Australia (March 2019)

Plants OF THE FUTURE

Ecologist and environmental scientist Dr Alessandro Ossola is working with Professor Michelle Leishman and a team of scientists to determine which plant species will thrive in our increasingly harsh climate

PHOTOS ALAMY, LEIGH STAAS, AARON DARC

Every summer sees new climate records being set in Australia. Droughts and heatwaves are becoming more frequent and intense. Some Australian cities and towns saw maximum daily temperatures this year soaring to almost 50°C. Others have been blanketed under sleepless summer nights, exceeding 35°C. Rephrasing Shakespeare's *A Midsummer Night's Dream*, heat and drought are rapidly becoming Australia's worst summer nightmare.

It is well known that all of this poses a great threat to the Australian people and public health, but what about our beloved plants? Plants are much like us. Some tolerate heat and lack of water surprisingly well, while others struggle as biological limits are met. This happens despite our passion and best gardening care.

Thus, the key issue is to understand which plant species will cope best with future climatic conditions, and in which planting contexts species should be used to increase their chance of success.

See more on Friday, Feb 15 at 7.30pm on ABC TV or catch on iview

SEEKING SURVIVORS

The issue of our changing climate keeps Australian scientists and horticulturists up at night, as we ask ourselves which species can safely be planted in our cities so they will survive climate change with minimal input of precious resources, such as water and fertilisers.

Other important points to determine are which species provide the greatest benefits in terms of cooling, opportunities for local biodiversity and the wellbeing of city dwellers, and if there are any new, neglected or forgotten species that could be used to replace those plants that are destined to fail under climate change. ►

ABOVE
Dr Alessandro Ossola and Dr Renee Prokopavicius use an instrument called a fluorometer to assess the vulnerability of plants to heat.

BELOW & RIGHT
Tree species before being subjected to artificial drought and heat; Professor Leishman and Dr Ossola spend time controlling plant growth and wellbeing for the project.

ABOVE & LEFT
Professor David Ellsworth and Associate Professor Linda Beaumont discuss findings from the *Which Plant Where* project with Josh Byrne for the TV segment; Dr Muhammad Masood measuring photosynthesis on *Hakea laurina*.

To answer these pressing questions, the not-for-profit research and development corporation, Hort Innovation, has teamed up with scientists from Western Sydney University, Macquarie University and the NSW Office of Environment and Heritage in a five-year research endeavour called the *Which Plant Where* project. The project sees the collaboration of more than 30 scientists, students, volunteers, interns, and industry and government partners from a variety of disciplines, ranging from ecology and eco-physiology to horticulture and urban planning.

The scientists are using computer models to predict species distribution based on the plant's natural climate. These bioclimatic models allow the researchers to assess tolerance to future climate for thousands of species, across a wide range of trees, shrubs, grasses, vines and herbs, including Australian natives and exotics.

The models suggest that many plant species will be moving southwards, with tropical and subtropical species more likely to succeed in temperate cities, such as Sydney and Melbourne. Other species, such as jacaranda, might completely disappear from their northernmost urban habitats. Those iconic purple blooms will probably cease tinting our tropical and subtropical suburbs in the future.

Species in the glasshouse are being exposed to artificial five-week droughts and heatwaves, peaking at 41°C, to measure their tolerance to drought and extreme heat. Plants have been sourced from every Australian state and territory to provide the widest possible range of species from different climatic conditions.

RIGOROUS TESTING

The scientists are also testing species in glasshouse experiments and in real-life plantings across Australian cities, in order to understand their climatic tolerance. This is critical to provide evidence that will help the horticultural industry, horticulturists and home gardeners adapt their plant selection in the face of climate change. It will also increase the diversity of species in our urban landscapes by reducing the risk of losing plants in a harsher climate.

Species in the glasshouse are being exposed to artificial five-week droughts and heatwaves, peaking at 41°C, to measure their tolerance to drought and extreme heat. Plants have been sourced from every Australian state and territory to provide the widest possible range of species from different climatic conditions.

Included in the trials are common plants and trees, such as the native brush box (*Lophosthemon confertus*), which is the most widely planted tree in Australia, and more uncommon species. Some of the well-known exotic plants being tested are the tulip tree (*Liriodendron tulipifera*), Chinese elm (*Ulmus parvifolia*), cherry plum (*Prunus cerasifera*) and London plane tree (*Platanus acerifolia*).

PHOTOS LEIGH STAAS, AARON DARC, ANDREW SULLY

The plants arrive mostly as tubestocks, which are grown on for two months to acclimatise and produce new leaves before being subjected to testing. In a few cases, more mature trees are used, and some plants are germinated from seed.

Not surprisingly, preliminary screening has confirmed that several of the species from Australia's iconic arid rangelands, such as boonaree, or inland rosewood (*Alectryon oleifolius*), will be better off in future hot and dry climates than the rainforest species, such as tuckeroo (*Cupaniopsis anacardioides*).

Australia is blessed with extraordinary native plant diversity which, under future climatic conditions, will provide untold opportunities for smart horticulture. Many of them will supplement tried-and-tested, resilient and commonly used exotic species, such as *Murraya paniculata*. Researchers will need to further explore the horticultural and economic potential of these plants for many years to come, trialling untested species and subspecies found in the great Australian outback.

POSITIVE OUTCOMES

The project will culminate in 2021 with the launch of an innovative plant-selection tool based on scientific data and evidence achieved. It will allow designers, landscape architects, gardeners, horticulturists and environmental managers to select from hundreds of plant species, based on their climatic, ecological, edaphic (influenced by the soil) and physiological traits.

To date, more than 56,000 trait data entries for more than 980 plant species have been collected from about 150 databases and sources from Australia and around the world, complementing our scientists' data from the field, the glasshouse and computer modelling.

Users will be able to personalise their plant selection experience for greater success, and to help Australia in creating greener and more sustainable cities that are resilient to climate change. GA

Join **Phil Dudman**, Horticultural Editor of ABC *Gardening Australia* Magazine, on a wonderful
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Appendix 13:

Fact sheet: Cooling benefits of urban trees

Published December 2019

Which Plant Where: Cooling benefits of urban trees

*As our **climate warms**, cities across Australia are experiencing longer and more intense **heatwaves**. This is in part due to the **urban heat island** effect, the result of higher temperatures in built up city-scapes, compared to surrounding areas (Figure 1).*

***Urban vegetation reduces** temperature in cities by reflecting incoming solar radiation, providing shade, reducing absorption of heat by surrounding man-made surfaces and via leaf evaporative cooling (Figure 2).*

***Cooling benefits** – the reduction in air and surface temperatures associated with urban vegetation – differ between species and are related to tree characteristics such as the width and density of the canopy and leaf characteristics such as size and leaf angle.*

The *Which Plant Where Project* - a five-year research program investigating how well current landscaping species will survive and thrive under the more extreme climates that Australia's cities will face - has assessed the cooling benefits associated with a wide range of tree species across Greater Sydney.

To do this we measured the temperature of air and standard surfaces (black and white tiles, and artificial grass) under the shade of tree canopies and compared these to temperatures in adjacent, unshaded conditions to calculate the "cooling benefit" associated with individual trees. We then evaluated relationships between cooling benefits and tree canopy characteristics such as height, width and density (leaf area index).

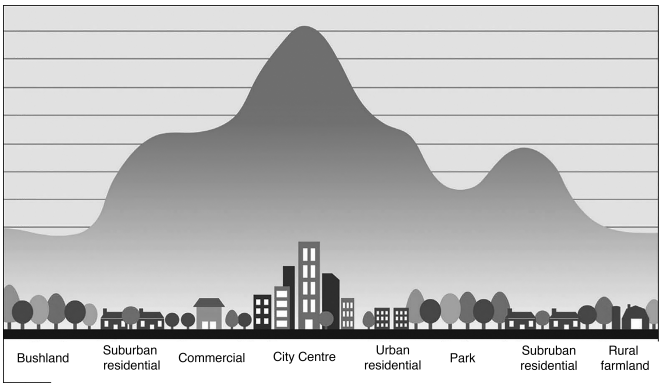

***Figure 1**. An **urban heat island** refers to the higher air temperatures typically observed in the built environment of urban and peri-urban areas when compared with the surrounding rural landscape. Man-made materials, including buildings, roads, pavement and other infrastructure typically warm up more than vegetation or soil during daylight hours, and re-radiate stored heat overnight, resulting in air temperature increases of 2 to 3 °C compared to surrounding areas. The urban heat island effect is most noticeable during summer and winter, and when winds are weak.*

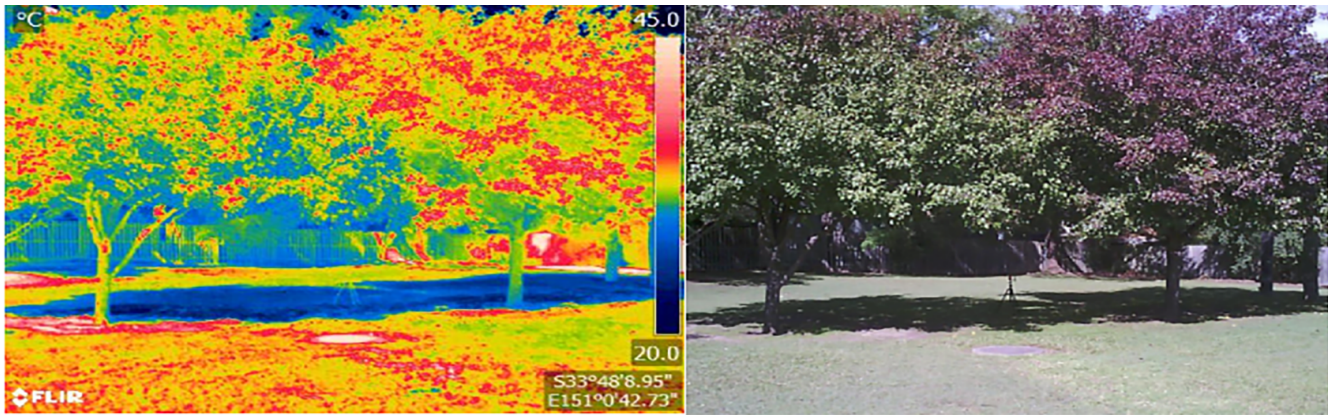

***Figure 2**. Thermal image (left) and photo (right) of urban trees in western Sydney, demonstrating variation in canopy temperatures and the cooling benefits associated with tree shade. Photo credits: Sebastian Pfautsch.*

Measurement campaigns were carried out in these local government areas (LGAs) in the Greater Sydney region:

- The City of Sydney
- Leichhardt (Inner West)
- Marrickville (Inner West)
- Parramatta City Council
- Penrith City Council

We surveyed 514 urban trees in street and park settings, finding an average air temperature reduction of 1.1 °C (± 0.67°C) and a maximum of 3.7 °C (± 0.3°C) under canopy shade, compared to the surrounding area (Figure 3). Temperature benefits provided by different tree species varied across study locations, reflecting size differences among individual trees and variation in ambient air temperatures at the time of measurement.

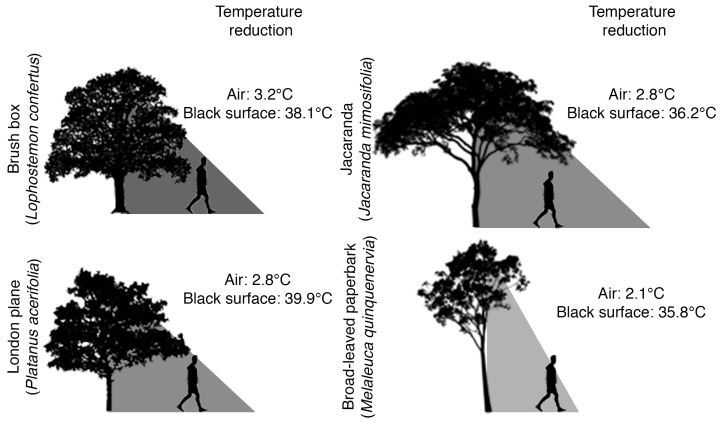

***Figure 3**. The amount of cooling is influenced by tree height and canopy density as well as contributions associated with leaf morphological and physiological traits. In this example, we present the maximum air temperature reduction recorded under canopy (compared to outside) for four dominant tree species in Parramatta, NSW Australia.*

Considerable temperature differences between full sunlight and canopy shade were also recorded for standard test surfaces - black and white tiles and artificial grass (all common features of the urban environment). Black tile temperatures were, on average, 28°C (maximum 45.1°C) cooler in canopy shade, compared to the same material in full sunlight; white tiles were, on average, 11.5 °C (max. 25.9 °C) lower and artificial grass was 27.9 °C (max. 51.9°C) lower when shaded by tree canopies. Measured temperatures of these standard surfaces demonstrate the enormous benefits of shade for reducing the heat load on man-made surfaces.

In summary, trees with wide, dense canopies were found to be generally more effective at reducing ground-level temperatures, with air and surface temperatures up to 3.7°C and 51.9°C cooler, respectively, under canopies compared to outside. Urban trees can therefore contribute substantially to reducing local air and surface temperatures, and thus human thermal comfort, in city-scapes, especially on hot summer days. Understanding relationships between species, canopy characteristics and cooling benefits - and how these differ in different planting contexts - can help inform species selection for cooling urban landscapes.

For more information

Please contact Prof. Sally Power (s.power@westernsydney.edu.au) or Leigh Staas (leigh.staas@mq.edu.au).

Which Plant Where is funded by the Hort Frontiers Green Cities Fund, part of the Hort Frontiers strategic partnership initiative developed by Hort Innovation, with co-investment from Macquarie University, Western Sydney University, the NSW Office of Planning, Industry & Environment and contributions from the Australian Government.

Appendix 14:

Fact sheet: Environmental suitability of horticultural plants

Published June 2020

*As our **climate warms**, cities across Australia are experiencing longer and more intense **heatwaves**. High temperatures enhance soil drying and increase the severity of **drought** – a phenomenon that will be most acutely felt in regions where rainfall is expected to decline in the future, such as southern and eastern Australia.*

***Urban vegetation reduces temperature** in cities (see WPW Factsheet 1, Cooling benefits of trees). Maintaining urban green spaces requires **selection of tolerant plant species** to survive future climate extremes. Some commonly planted species may become unsuitable (Figure 1).*

Which Plant Where is a five-year research project investigating how well current and new prospects for horticultural species will survive and thrive under the more extreme climates that Australia's cities will face.

We assessed the physiological tolerances of a wide range of tree/shrub/grass species **to identify tolerant species**, including some not commonly available ones.

Using standardised glasshouse experiments (Figure 2), we screened over 110 horticultural species and varieties for heat and drought tolerance. Plants received a moderate drought and then a 6-day heatwave with a daily high temperature of 41 °C. More severe conditions may be field-tested in the future.

***Figure 1**. Dieback of* Tristaniopsis *cv. Luscious (left) and willow bottlebrush (*Callistemon*, right) in western Sydney in January 2020. The 2019-2020 summer began as the driest on record and with 12 days over 40 °C, including the highest temperature ever recorded in the Sydney basin (48.9 °C).*

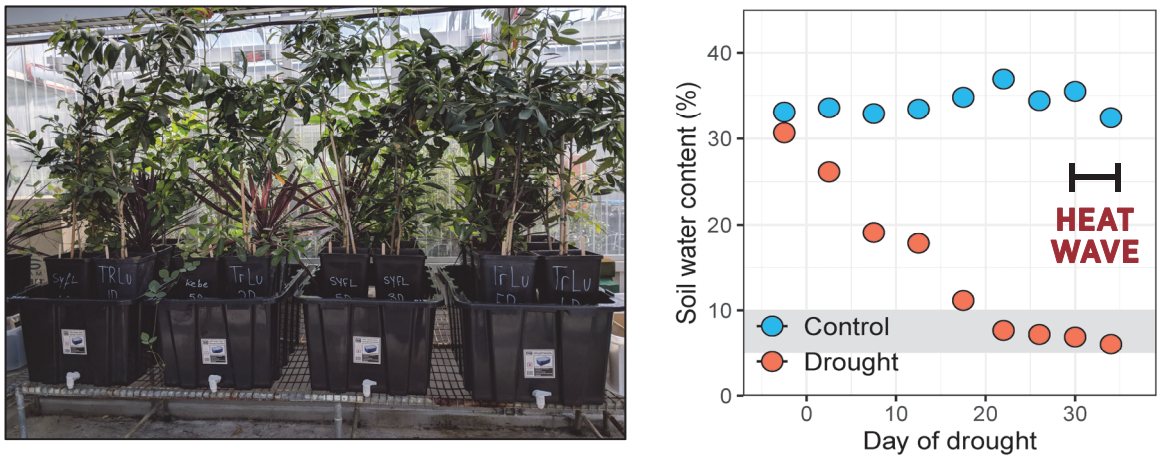

***Figure 2**. Potted plants undergoing gradual drought treatment in glasshouse (left). The experimental treatment exposed both well-watered control plants and droughted plants to a six-day heatwave (right).*

We combined data from over 10,000 measurements to rank horticultural species/varieties from our experiments according to their overall drought tolerance level.

Drought tolerant – plants suitable to periods without rain or irrigation

Drought-tolerant species have thick and/or small leaves with high tissue density and will only wilt after prolonged drought. We measured these in the glasshouse, and ranked species with them.

We classified 53 of 113 species tested as either drought-tolerant or moderately drought tolerant. These plants have what it takes to survive a relatively long-duration of rain deficits: long periods between a good soaking. These plants can be appropriate for dry sites with irregular rain and low water supply/very well-drained. Some of them require arid, low-rain conditions and won't grow well in wetter climates.

Selection of tolerant species does not prevent the need for good planting practices and irrigation, especially during the establishment phase. But don't over-water: some of these can suffer pathogens and/or root rot if kept too wet.

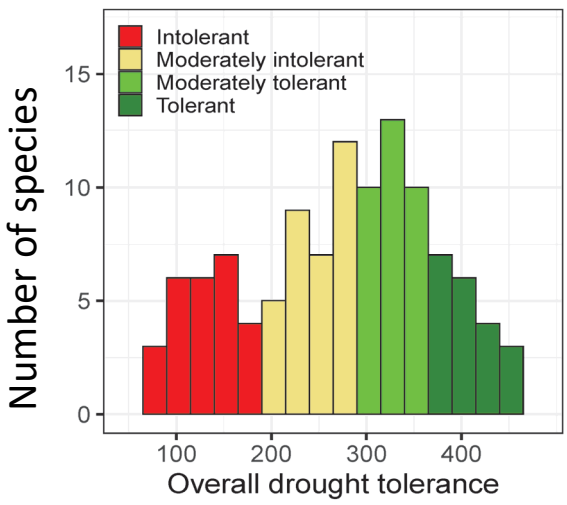

***Figure 3**. Bar-graph of the distribution of plants we evaluated into 4 different drought tolerance groups based on their leaf and stem characteristics. Species falling in the green bars (light or dark green) were judged to have good drought tolerance. Species in the tolerant category at right.*

DROUGHT-TOLERANT PLANT EXAMPLES:

Acacia brachybotrya, Grey or silver wattle
Alectryon oleifolius, Boonaree or inland rosewood
Buckinghamia celsissima, Ivory curl
Callistemon viminalis, Weeping bottlebrush
Eremophila maculata, Spotted emu bush
Flindersia maculosa, Leopardwood
Geijera parviflora, Wilga or native willow
Hakea laurina, Pin-cushion hakea or kodjet
Murraya paniculata, Murraya or orange jessamine
Notelaea microcarpa, Native olive or mock olive
Ophiopogon japonicus, Mondo grass
Photinia robusta, 'Red Robin' Photinia
Pistacia chinensis, Pistachio or Chinese pistache
Pittosporum angustifolium, Native apricot
Pittosporum tobira, Laurel or Japanese cheesewood
Podocarpus elatus, Plum pine or Illawarra plum
Pyrus calleryana, Callery pear
Rhaphiolepis umbellata, Yeddo or Indian hawthorne
Sarcopteryx stipata, Steelwood
Syzygium anisatum, Ringwood or aniseed tree
Tristaniopsis laurina, Kanooka, water gum, cv. 'Luscious'
Ulmus parvifolia, Chinese elm or lacebark elm
Xylosma congestum, Shiny xylosma

Tolerance needs some caution: **even drought-tolerant species can be vulnerable to the combination of heat and drought stress** – at least while young and unestablished.

Suitable for cooler and wetter locations

When drought stress coincides with heatwaves, plants have less water for evaporative leaf cooling. This can increase leaf temperature by 2-8 °C and risks exposure to killing temperatures, which threatens plant survival (Figure 1).

We found that >12 species were vulnerable to the combination of heat and drought stress in our glasshouse experiments (Figure 4) – they tended to have a lower critical temperature for death, and showed damage in experimental heatwaves. **They can still be used urban situations with appropriate care – grown in shady or cooler microsites, or more coastal areas** into the future. In urban spaces, care to protect from afternoon sun and/or irrigation during extremes should help.

EXAMPLES OF PLANTS VULNERABLE TO HEAT & DROUGHT:

Arthropodium cirratum, Renga lily, N.Z. rock lily

Banksia robur, Swamp banksia

Cordyline australis, Cabbage-palm or cabbage-tree

Cupaniopsis anacardioides, Tuckeroo

Goodenia ovata, Hop goodenia

Hydrangea macrophylla, French or bigleaf hydrangea

Nandina domestica, Nandina, heavenly bamboo

Pittosporum bicolor, Cheesewood or banyalla

Pomaderris apetala, Common dogwood

Stenocarpus sinuatus, Firewheel tree, white Silky Oak

Syzygium wilsonii, Powderpuff lilly pilly

Viburnum tinus, Laurustinus

***Figure 4**. Leaf damage with heat and drought stress. Photos: R. Prokopavicius.*

Some plant species have **low drought tolerance** but utilise **drought avoidance strategies** to survive periods of water stress. For example, plants with **succulent leaves or water storage organs** can survive in dry, arid environments. **Drought-deciduous species** shed leaves during periods of drought, but can quickly flush leaves after rainfall. These drought-avoiding species are worth considering for urban plantings:

- *Brachychiton populneus*
- *Brachychiton rupestris*
- *Cynodon* 'TifTuf'
- *Delonix regia*
- *Erythrina vespertilio*
- *Melastoma affine*
- *Melia azedarach*
- *Plectranthus argentatus*
- *Stenotaphrum secundatum*
- *Toona ciliata*
- *Tulbaghia violacea*

For more information

Please contact Prof. David Ellsworth (d.ellsworth@westernsydney.edu.au) or Leigh Staas (leigh.staas@mq.edu.au).

Which Plant Where is funded by the Hort Frontiers Green Cities Fund, part of the Hort Frontiers strategic partnership initiative developed by Hort Innovation, with co-investment from Macquarie University, Western Sydney University, the NSW Office of Planning, Industry & Environment and contributions from the Australian Government.

Appendix 15:

How we calculated planting co-benefits in Which Plant Where

https://whichplantwhere.com.au/resources

How we calculated planting co-benefits in Which Plant Where

By Alessandro Ossola, Samiya Tabassum, Paul Rymer, Sally Power & Michelle Leishman, September 29th 2021

In the Which Plant Where plant selection tool we calculated key co-benefits that species and plantings can provide to cities. For each species palette, co-benefits are averaged when you select at least 10 species and/or cultivars to be planted.

SHADE VALUE

The shade value of each tree species has been evaluated by calculating a Shade Index at Maturity, which is a categorical classification of the maximum amount of shade a tree species can provide based on its maximum height and canopy width. Note that this is a relative estimate as the shading ability of trees is also influenced by other local factors such as leaf area index (LAI), tree health and angle of the sun changing with seasons.

CO-BENEFIT UTILITY: Shade value is a useful trait to consider when designing urban plantings for the medium and long-term. Tree species with higher shade index can cast greater shade during the day by having larger canopies and/or by being taller trees. As different species can have different growth rates, shade values have to be considered in relation to each species' average growth rate to ensure shade targets are achieved within the intended period. The Shade value represents a relative measure of the 'shade footprint' that different species of trees can cast at maturity, and as such, it is useful when selecting tree species to achieve shade benefits. Note that during winter, you might want to select tree species that minimise the amount of shade and allow sunlight in, such as deciduous and semi-deciduous species. This index does not include variability due to leaf area index (e.g., canopy openness/closeness), tree health (e.g., the presence of foliar diseases), and seasonal variability in the sun position.

METHODOLOGY: The Shade value at maturity (SV_{mat}) is calculated from the maximum canopy width (CW_{max}) and the maximum tree height that a species can reach at maturity on average (TH_{max}). The Shade value at maturity (SV_{mat}) is firstly averaged from i) the average vertical canopy shade projection at midday ($\Pi\ (CW_{max}/2)^2$) that depends on tree canopy width, and ii) the lateral canopy shade projection at sunset/sunrise (TH_{max} * CW_{max}) that depends on both canopy width and tree height (Fig. 1).

The differentiation of these two values has been introduced recognising that some tree species might have the same vertical shade projection on the ground at midday but vastly different shade casting when the sun is not at the zenith (e.g., *Catalpa bignonioides and Araucaria heterophylla* might cast similar shade on the ground when the sun is high in the sky because of their similar canopy widths, but *Auracaria* might project a longer shade at sunset/sunrise being a taller tree than *Catalpa*, thus having a greater shade value).

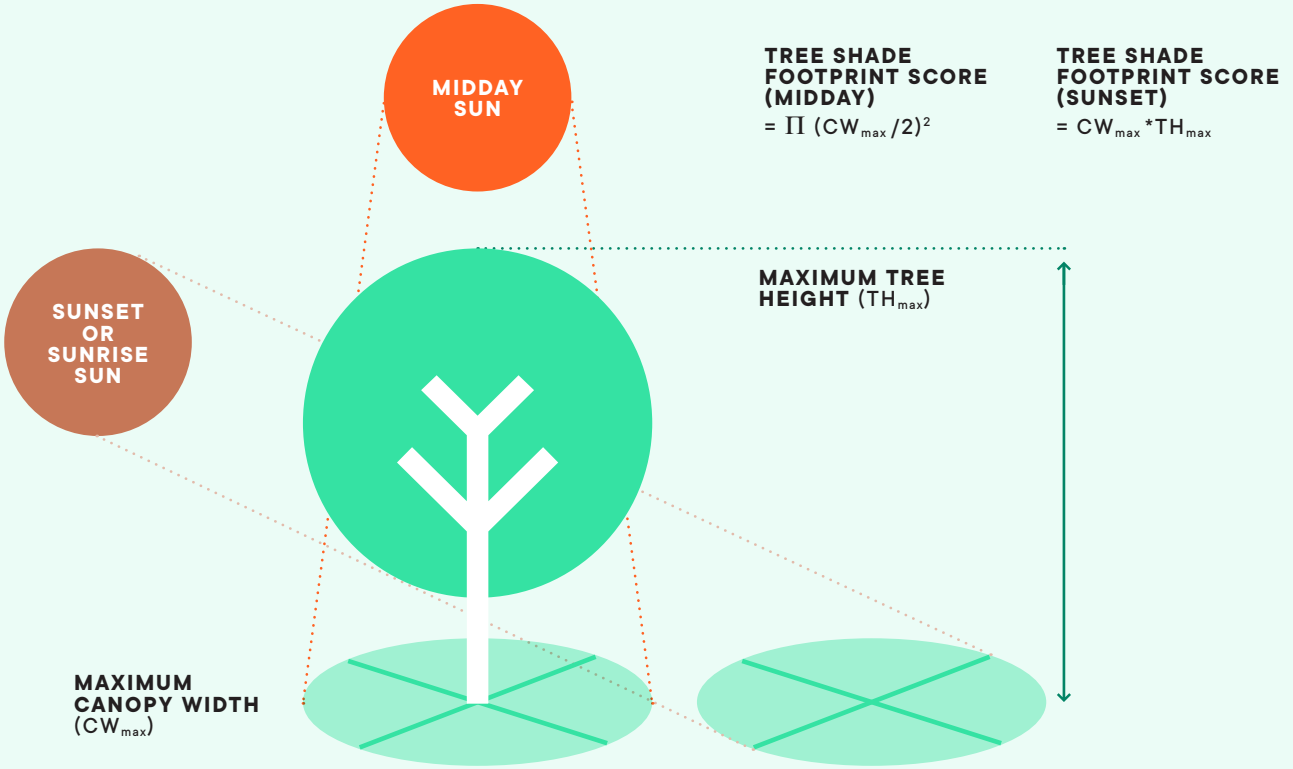

FIGURE 1 Schematic representation of the calculations used to estimate Shade Values

Averages are then sorted into four categorical classes, representing **four levels of Shade value**, following the distribution of values of all the Which Plant Where tree species:

"Very Low" – first quartile of distribution (i.e., from minimum value to 25th percentile)

"Low" – second quartile of distribution (i.e., from 25th to 50th percentile)

"Medium" – third quartile of distribution (i.e., from 50th to 75th percentile)

"High" – fourth quartile of distribution (i.e., from 75th percentile to maximum value)

To calculate the Shade Value of your personalised species palette in the Which Plant Where tool, the enumerated shade value for each species is averaged to calculate the overall shade value of the palette when this includes a minimum of 10 plant species and varieties.

NOTE: It is assumed that tree canopies are circular when the shade footprint is projected onto the ground. Raw maximum canopy width and tree height data were obtained from a number of sources.

BIODIVERSITY VALUE

Biodiversity value is an indication of the capacity of plants to provide food, resources and/or habitat for various groups of fauna and wildlife. Biodiversity value is estimated using an index ranging from 1 (low biodiversity value) to 5 (high biodiversity value), based on the number of types of species (pollinators, insects, birds, lizards/ native mammals) known to use that plant species for resources such as pollen, nectar, fruits, habitat, nesting, etc. Plant species are also assigned a habitat value that is not necessarily linked to a particular group of wildlife species using each plant (e.g., leaf litter used by soil fauna).

CO-BENEFIT UTILITY: The biodiversity value is a useful trait to consider when designing plant assemblages for urban spaces, as maximising biodiversity benefits can increase ecosystem services - such as pollination – while leading to the green space being more engaging to the public. As urbanisation leads to greater tree canopy loss and removal of habitat, it is important that urban green spaces provide a refuge and resources for native fauna to help alleviate negative impacts of urbanisation. Many features of popular urban horticultural plants can provide excellent resources for native species. For example, shrubby Acacias and Grevilleas often provide excellent nesting habitat for small native bird species. To ensure that pollinators such as butterflies and bees have ample food (i.e., nectar, pollen) throughout the year, it is a good idea to select many species that flower at different times during the year. The same is true for frugivorous species, such as birds, that can feed on different fruits and seeds provided by different plant species over the year.

METHODOLOGY: Information on whether plants provide habitat and/or food resources for five different types of fauna and habitat value (pollinators (i.e., bees and butterflies), insects (other non-pollinator insects), lizards/ mammals, birds and habitat) was obtained from a variety of sources. Each plant species is assigned a value of 1 for each faunal group that it provides resources for, beside a baseline habitat value of 1. The biodiversity index is estimated as the sum of all singular biodiversity scores for each animal group. Thus, the index ranges from 1 (low biodiversity value) to 5 (high biodiversity value) based on the number of fauna types known to use that plant species for resources, habitat, etc.

Pollinators

Birds

Insects

Lizards

Mammals

Habitat

Each species' biodiversity score is used to calculate the biodiversity value of each personalized species palette as the average biodiversity score of all the species included in the palette, when a minimum of 10 plant species and varieties are selected.

CARBON VALUE

The carbon value for each tree species has been estimated by calculating a Carbon Index at maturity which is a categorical value representing the ability of trees to accumulate carbon in their biomass. Larger trees have greater benefits in sequestering and storing carbon over time, while promoting carbon sequestration in the soil through decomposition processes.

CO-BENEFIT UTILITY: Carbon value at maturity is a useful trait to consider when designing urban plantings for the medium and long-term, when carbon storage to offset CO^2 emissions is an objective. Bigger tree species can store more carbon in their aboveground and belowground (i.e., roots) biomass, while promoting carbon sequestration in the soil via decomposition and root exudates. As different tree species have different growth rates, carbon index values must be considered in relation to each species' average growth rate to ensure targets are achieved in the intended period. Also, long lived tree species can sequester carbon for longer periods of time if trees are retained and allowed to grow to maturity.

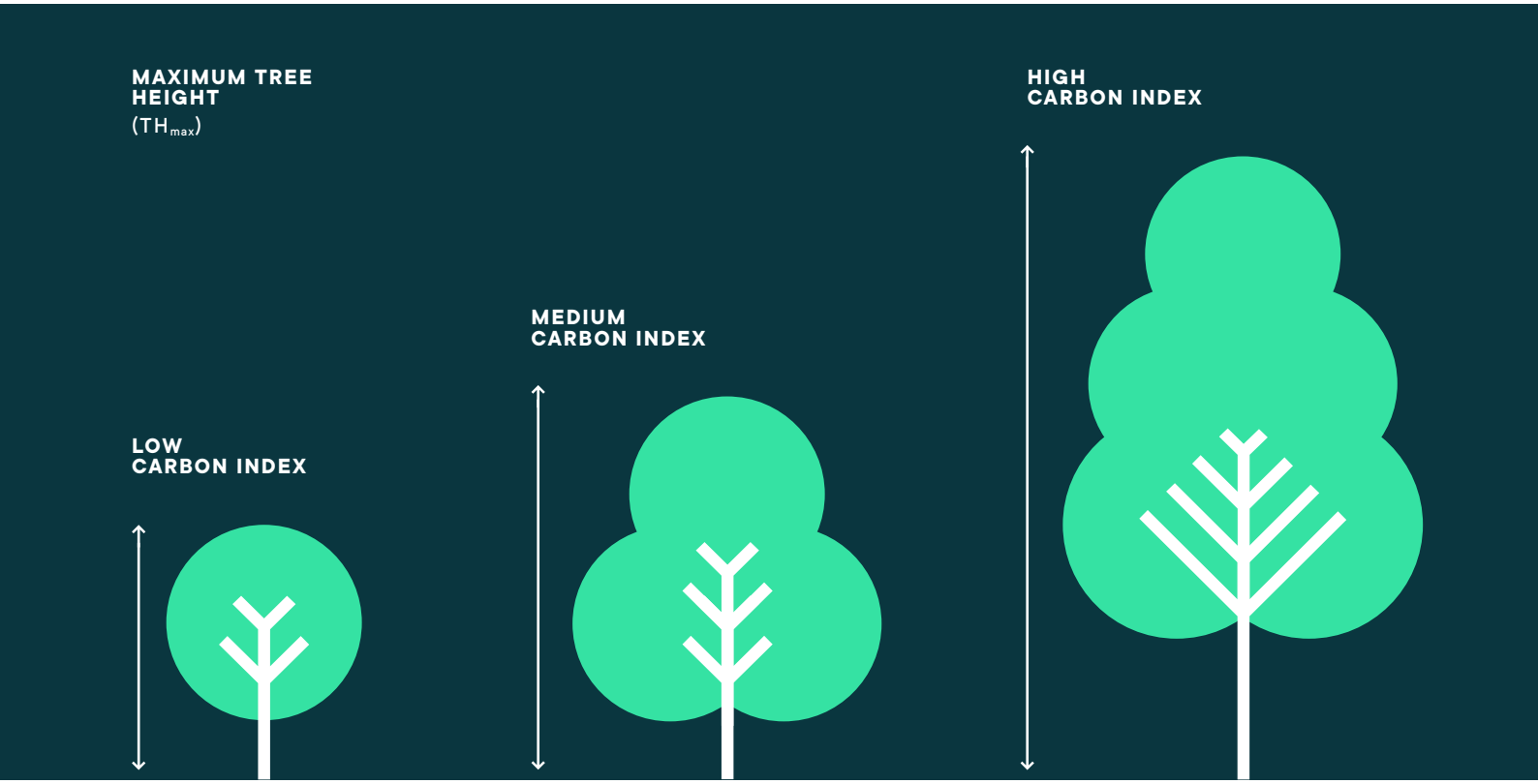

FIGURE 2 Schematic representation of the approach used to calculate Carbon Value

METHODOLOGY: Carbon value at maturity is calculated from the maximum tree height that a species can reach when aging, on average (TH_{max}). Raw maximum tree height data (Fig. 2) were obtained from a number of sources.

TH_{max} values are sorted into three categorical classes of **Carbon Value**, following the distribution of values of all the Which Plant Where tree species:

"Low" – first third of distribution (i.e., from minimum to 33rd percentile)

"Medium" – second third of distribution (i.e., from 33rd to 66th percentile)

"High" – last third of distribution (i.e., from 66th percentile to maximum value)

To calculate the Carbon Value of your personalised species palette in the Which Plant Where tool, the enumerated carbon value for each species is averaged to calculate the overall value of the palette when this includes a minimum of 10 plant species and varieties.

Appendix 16:

How we calculated canopy cover in Which Plant Where

https://whichplantwhere.com.au/resources

Which Plant Where

How we calculated canopy cover in Which Plant Where

By Alessandro Ossola & Michelle Leishman, September 28th 2021

In the Which Plant Where plant selection tool we calculate the maximum canopy cover that your plantings can provide to cities. For each species palette, the maximum canopy cover is calculated based on the maximum canopy width each species can reach at maturity to help you plan for the future of your urban forest.

CANOPY COVER VALUE

Canopy cover is the maximum area projected by a species' canopy onto the ground at maturity (Fig 1). Canopy cover at maturity values are expressed in square metres (m^2) and are calculated for trees as well as selected shrub species that can have a tree habit.

Canopy cover at maturity is a useful trait to consider when designing urban plantings for the medium and long-term. Plantings in confined spaces (e.g., below powerlines, small soil volumes, etc.) might benefit from the selection of species with low/medium canopy cover at maturity. On the other hand, large urban forestry projects designed to provide shade and cooling benefits will benefit from the selection of climatically-suitable species with large canopy cover at maturity. As different species can have different growth rates, canopy cover (at maturity) values have to be considered in relation to each species' average growth rates to ensure canopy cover targets are achieved within the intended period.

METHODOLOGY

FIGURE 1 Canopy cover at maturity (CCmat) is calculated from the maximum canopy width that a species can reach at maturity (CWmax) following the equation: CCmat = Π $(CWmax/2)^2$. It is assumed that canopies are circular when projected onto the ground. Raw maximum canopy width data were obtained from a number of sources.

Appendix 17:

How we calculated planting diversity in Which Plant Where

https://whichplantwhere.com.au/resources

How we calculated planting diversity in Which Plant Where

By Alessandro Ossola & Michelle Leishman, 28th September 2021

In the Which Plant Where plant selection tool we provide an estimate of the planting diversity of each palette of species when you select at least 10 species and/or cultivars to be planted. High planting diversity is important to create resilient and sustainable urban greenspaces while helping to sustain biodiverse and nature-rich cities (read more about 'The many faces of urban plant diversity' on the 'Resources' page).

THE 10:20:30 RULE

The 10:20:30 Rule is a simple tool from urban forestry to measure the diversity of urban plantings (Santamour, 1990), and over the decades has helped urban foresters, planners and designers to significantly increase the diversity of urban forests globally (Kendal *et al.*, 2014). Despite being originally devised for urban tree species, in Which Plant Where we extend the use of the 10:20:30 rule and apply this approach to all the plant growth forms, including trees, to provide a comprehensive measure to assess differences and values of diversity among species lists, palettes and plantings.

The rule is composed of 3 simple criteria:

CRITERION 1: We want you to plant at least 10 different species or cultivars. This can ensure the base for a large and diverse plant palette.

CRITERION 2: No more than 20% of selected species are from the same genus. If we select 10 plants from 2 genera, this criterion is not satisfied. Your list of 10 must not have more than 2 species from a single genus, so if you included plants from 5 or more genera we are good to go and this criterion is met!

CRITERION 3: No more than 30% of selected species are from the same family. If all the species we select come from a single family, this criterion is not satisfied. However, if your list of 10 species includes plants from 3 or more genera you are doing a great job in picking biodiverse plantings!

Plantings can be diverse in the genera, species and cultivars used (Credit: AO)

HIGH VS LOW PLANTING DIVERSITY

SCORING METHODOLOGY:
Based on the 10:20:30 rule, each palette containing at least 10 species is given a HIGH, MODERATE or LOW planting diversity value based on the following criteria:

- If the species list fulfils all **3 criteria of the 10:20:30 rule** (no more than 10% of any particular species/cultivar, no more than 20% of any one genus or no more than 30% of any single family), then its plant diversity value is **HIGH**.

For instance, in the example below (Fig. 1) we have a highly diverse palette of 10 species all coming from 10 different genera and even 10 different families.

- If the species list fulfils any **2 of the 3 criteria** (no more than 10% of any particular species/cultivar, no more than 20% of any one genus or no more than 30% of any single family), then its plant diversity value is **MODERATE**.

- If the species list fulfils only **1 of the 3 criteria** (no more than 10% of any particular species/cultivar, no more than 20% of any one genus or no more than 30% of any single family), then its plant diversity value is **LOW**.

For instance, a palette composed of 10 different species from the genus Acacia also comprises species from a single botanic family (Fabaceae), and as such, it is deemed as a low diversity planting palette (Fig. 2).

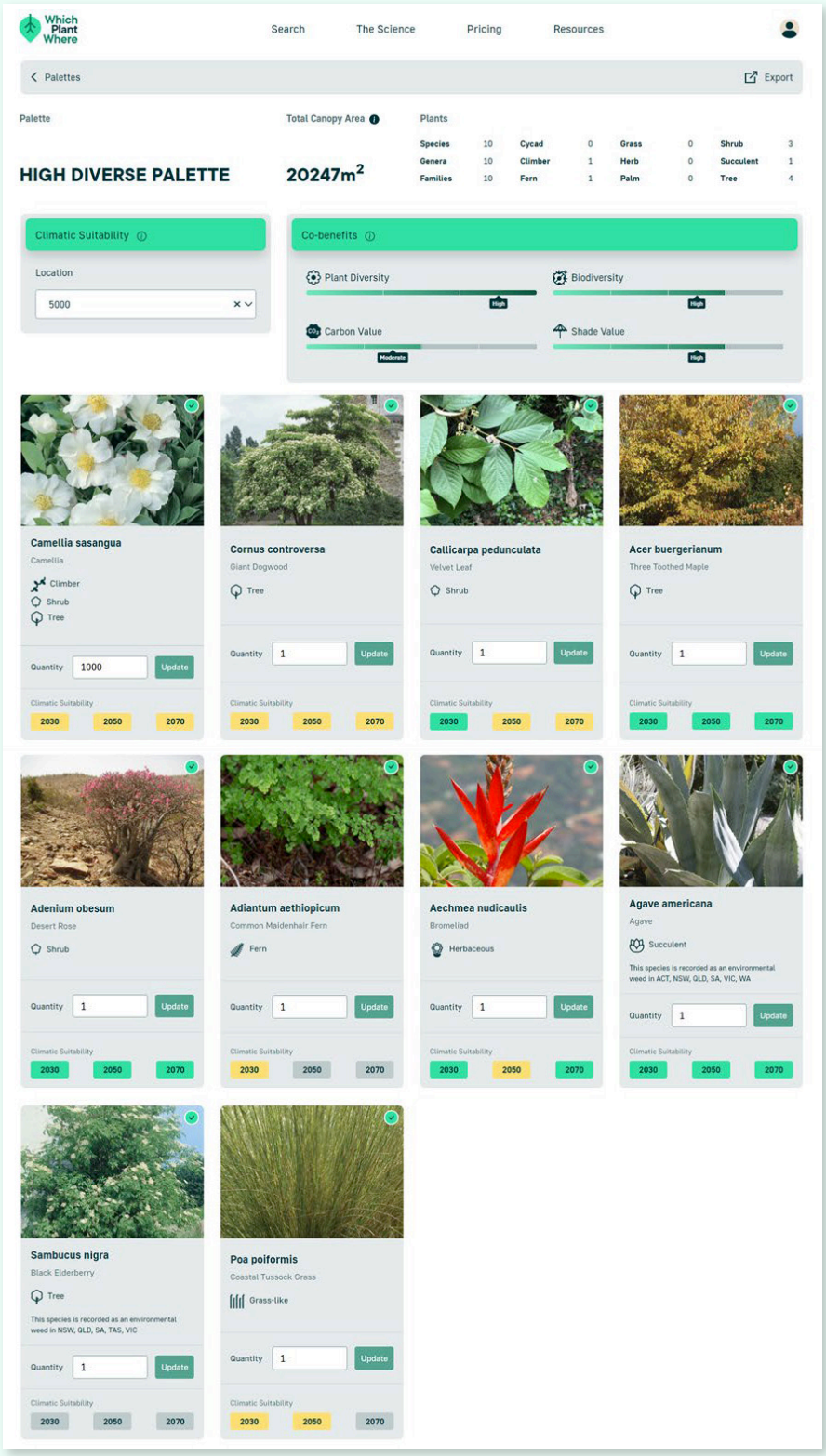

FIGURE 1 Example of a hypothetical high-diversity plant palette containing 10 species belonging to 10 different families, 10 different genera and at least 10 different species/cultivars. Because all the 3 criteria above are satisfied, this species palette has a HIGH planting diversity.

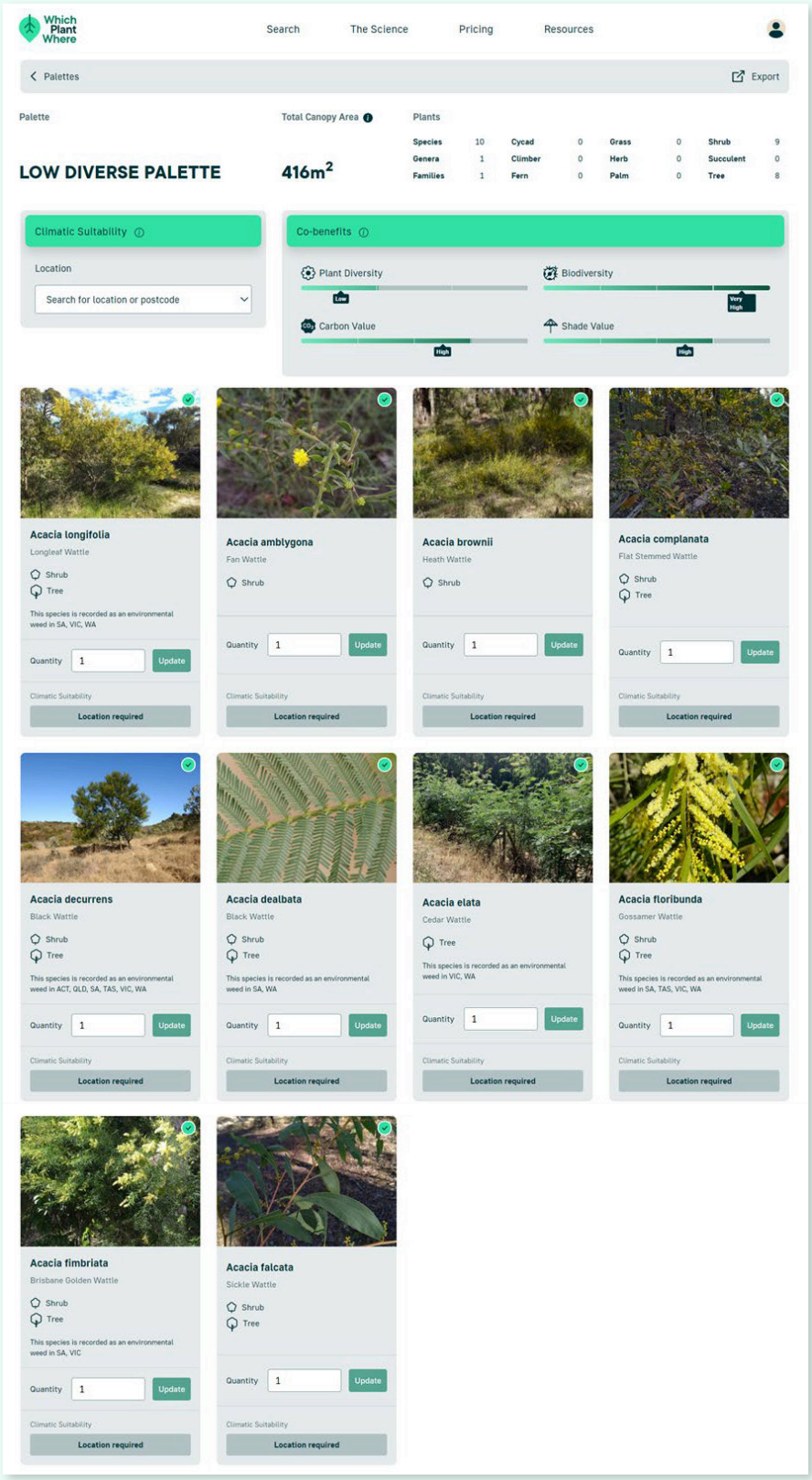

FIGURE 2 Example of a hypothetical low-diversity plant palette containing 10 plant species belonging to a single family and one genus. Because only 1 criterion above is satisfied, this species palette has a LOW planting diversity.

REFERENCES

Santamour, 1990. Trees for urban planting: diversity, uniformity, and common sense. Proceedings of the Seventh Conference of the Metropolitan Tree Improvement Alliance (METRIA) (1990), pp. 57-65.

Kendal, D., Dobbs, C., Lohr, V.I., 2014. Global patterns of diversity in the urban forest: Is there evidence to support the 10/20/30 rule? Urban Forestry & Urban Greening, 13: 411-417. https://doi.org/10.1016/j.ufug.2014.04.004

Appendix 18:

What is a weed and how are they identified in Which Plant Where

https://whichplantwhere.com.au/resources

What is a weed and how are they identified in Which Plant Where

By Anthony Manea, Samiya Tabassum & Michelle Leishman, 1st September 2021

With the emergence of global travel and trade, the movement of plant species out of their native environment into new environments has increased dramatically. In some cases, the new environments provide favourable growth conditions for the introduced plant species and also lack the pests and diseases that have kept those plant species in check in their native environment. It is often under these conditions that weeds are born. In Australia, approximately 10% of the many thousands of introduced plant species have become naturalised (i.e., formed self-sustaining populations), with only a small percentage of these going on to becoming problematic invaders.

WHAT IS A WEED?

A weed is a plant species that has been introduced into a new environment and becomes invasive, outcompeting and displacing the desired species within that environment. Fast growth rates, high viable seed production, vegetative reproduction and long distance propagule dispersal are all characteristics that are typical of weeds. It is important to note that weeds are not always introduced from other countries. In Australia, there are many cases where native plant species have become weeds when introduced into a new environment. For example, *Acacia longifolia*, which is native to the east coast of Australia, has become invasive not only in Portugal and South Africa but in parts of Western Australia as well.

Above Image: Native to South America, *Tradescantia fluminensis* was originally introduced to Australia as a garden ornamental and has since become a weed that invades bushland. Image courtesy: Forest and Kim Starr (via Wikimedia Commons).

WHY DO WE CARE ABOUT WEEDS?

Weeds exist in most environments and have a range of economic, environmental and social impacts. For example, weeds pose one of the greatest threats to biodiversity globally, along with land-use change and climate change. Within Australia, weeds are continuing to spread fast despite billions of dollars being spent on their control and management annually. The most problematic weeds have been listed for priority management under legislation at the state- and national-level, including the 32 Weeds of National Significance (known as WONS, https://weeds.org.au/).

WEEDS AND THE URBAN ENVIRONMENT

The impact of weeds in the managed urban environment is much less than in natural and agricultural environments. This is due to a combination of the challenging growing conditions in urban environments and intensive landscape maintenance by humans. Why then do we care about weeds in the urban environment? We care because urban environments act as a major gateway for weeds to escape into natural and agricultural environments. In fact, up to 70% of the weed species in Australia were historically introduced as garden ornamentals (sometimes referred to as garden escapes). Although modern biosecurity measures have significantly reduced this introduction pathway, plant species are still being introduced regularly. Therefore, it is critical that we are extremely mindful of what we plant in our urban environments because it may have devastating impacts, beyond our managed urban landscapes.

HOW WE CLASSIFIED WEEDS FOR WHICH PLANT WHERE

As well as the Weeds of National Significance, each state and territory in Australia has its own legislated list of prohibited weeds. These lists are unique to each state and territory and reflect species which have been declared, meaning that they are either prohibited to be brought into the state/territory, or their presence in the state/territory is strictly controlled. Because these lists are unique to each state/territory, a species may be declared as a weed in one state/territory but be completely fine to purchase and plant in a different state/territory.

Camphor laurel *(Cinnamomum camphora)* was introduced into Australia from Asia in 1822. In the past, it was a popular species to plant in urban environments (left photo). It has since become invasive in both urban (middle photo) and natural environments (right photo). Images courtesy: A Manea

The Which Plant Where selection tool uses information from state/territory declared weed lists to identify declared species. If a plant is a declared species in any state/territory, a message will appear near the top of the species page indicating which state(s)/territory(ies) it is declared in. Below are the links to the various state and territory lists for declared weeds:

NSW
weeds.dpi.nsw.gov.au/

QLD
business.qld.gov.au/industries/farms-fishing-forestry/agriculture/land-management/health-pests-weeds-diseases/weeds-diseases/invasive-plants/prohibited

business.qld.gov.au/industries/farms-fishing-forestry/agriculture/land-management/health-pests-weeds-diseases/weeds-diseases/invasive-plants/restricted

VIC
vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/weeds_listing2_a

SA
https://pir.sa.gov.au/biosecurity/weeds_and_pest_animals/weeds_in_sa

WA
agric.wa.gov.au/organisms

TAS
dpipwe.tas.gov.au/invasive-species/weeds/weeds-index/weeds-index-alphabetic-by-scientific-name

NT
nt.gov.au/__data/assets/pdf_file/0016/252133/declared-weeds-in-the-nt.pdf

ACT
legislation.act.gov.au/di/2015-59/current/pdf/2015-59.pdf

Acacia baileyana (Cootamundra Wattle) is native to the inland parts of southern New South Wales. It has been widely cultivated in parks, gardens and as a street tree. It has been listed as a declared weed in the Australian Capital Territory (ACT) and has become naturalised (formed self-sustaining populations) in many other states. Image courtesy: Thennicke, Wikimedia Commons.