# Valuing the Waite Arboretum, South Australia

An i-Tree Ecosystem Analysis


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September 2017

*"It is now generally admitted by all enlightened people that trees play a very important part in the general prosperity of any country, and that, by the amount of attention paid by its inhabitants to their cultivation, so may the physical and intellectual standard of the people be estimated."*

John Ednie Brown, Sylviculturalist and Conservator of Forests South Australia, 1881

# Contents

Cover image: Measuring tree height - Dragon Tree *Dracaena draco* Waite Arboretum Tree ID #467– icon of Waite Arboretum. Photo: J. Gardner 2002

Wild Pear - *Pyrus pyraster* Waite Arboretum Tree ID #202 Photo: J. Gardner

## Figures



## Tables

# Executive Summary

Green infrastructure, particularly the urban forest, is increasingly recognised for its multiple benefits. These include amelioration of urban climate extremes, conservation of biodiversity, reduction of energy consumption through shading buildings, reduction in air, water and noise pollution, avoidance of runoff and soil erosion through rainfall interception, mitigation of heat island effects, increasing property and aesthetic values, economic prosperity and tourism, wildlife habitat, and improving physical and mental health and wellbeing. Urban forests such as the Waite Arboretum and other green infrastructure such as parks and gardens, street trees, playing fields, vertical and rooftop planting, play a critical role in maintaining healthy urban environments and are essential assets that keep our cities liveable.

The University of Adelaide's Waite Campus occupies 205 hectares of which 10 hectares are buildings and carparks. The rest is urban forest including the 27 hectare Waite Arboretum, 121 hectare Waite Conservation Reserve of Grey Box Grassy Woodland, a Nationally Endangered Ecological Community, and other green space such experimental orchards, vineyards, crops and sports field.

The purpose of this report is to raise community awareness of the Waite Arboretum, its trees and their many benefits, and to promote visitation, participation, use, appreciation and support of this significant rain-fed scientific collection. The report also makes recommendations of species which have performed well in the Waite Arboretum and provide the greatest environmental benefits. This will inform sustainable species selection for our urban forest of the future.

The 'Open-source' i-Tree Eco version 6 software, developed by the U.S. Forest Service, was used to assess, and assign values to, some of the environmental benefits of the University of Adelaide's Waite Arboretum. Other benefits such as biodiversity conservation are widely acknowledged but are difficult to quantify.

A survey of trees at the Waite Arboretum collected standardised field data on 1,255 specimens representing 601 species. The structural value of the surveyed trees (50% of the Waite Arboretum collection) was calculated to be A$13 million.

Additional structural and functional values of the surveyed trees were:

- ✓ Carbon storage: 1,167 tonnes (A$26,600), equivalent to annual carbon emissions from 910 vehicles or 373 single-family houses
- ✓ Air pollution removal ($O_3$, CO, $NO_2$, $SO_2$ and particulate matter <2.5 microns): 1.2 tonnes / year (A$4,840 / year) equivalent to annual emissions from 160 vehicles or 36 single family homes
- ✓ Carbon sequestration: 34.3 tonnes/ year (A$783 / year)
- ✓ Oxygen production: 91.5 tonnes / year
- ✓ Avoided runoff: >1,072 cubic metres / year (A$2,420 / year)

The environmental benefits of every specimen surveyed is available on ArcGIS Online maps.

This report is in two parts. The first part presents some of the quantifiable ecosystem services provided by 1,255 trees surveyed. The second part presents some of the many intrinsic environmental, aesthetic, social, educational and cultural benefits provided. We conclude the full value of the Arboretum is much more than the assigned structural value.

# 1 Introduction

## 1.1 Waite Arboretum

Waite Arboretum was established on land bequeathed to The University of Adelaide in 1914 by pastoralist and businessman Peter Waite. His fine residence set on 54 hectares of agricultural and grazing land, together with substantial funds, remains one of the most generous benefactions in the history of South Australia (Figure 1). Under the terms of the gift, the eastern half of the estate is to be used for the purposes of study and teaching in fields of agriculture, botany, entomology, veterinary science, horticulture, and forestry. The western half is to be a park or garden for the enjoyment of the public. Waite asserted the importance of applied science, if agriculture and forestry were to flourish in the future, so it was decided that the park would take the form of an experimental collection. Planting began in 1928 and from the outset good records were kept of every specimen. The evaluation of the performance of a wide variety of species in our Mediterranean climate of hot, dry summers and cool, wet winters has wide applicability to other areas in south-eastern Australia. This information is becoming increasingly valuable in view of climate change.

Waite Arboretum occupies 27 hectares and comprises 2,500 specimens from around the world growing on a rainfall of 618 mm[1] without supplementary watering after establishment[2]. The collection comprises over 1,000 taxa representing 215 genera in 61 families, and includes many species with international conservation status. In keeping with the spirit of the bequest, Waite Arboretum is open free to the public daily, dawn till dusk. A free Waite Arboretum App for mobile devices was developed in 2015. The App enhances the visitor experience by providing the label information of every specimen in the collection using the 'Near Me' function. This function provides location and tracking capacity for the visitor's movements throughout the Arboretum. For many of the trees, descriptive text and images of flowers, fruit and other features which may not be present at the time of the visit, are also available. Other functionalities of the app include 'Search' (using a choice of Scientific and/or Common Names, Distribution and Tree ID number), 'Themed Walks' and information about wildlife, sculptures and other features of interest.

## 1.2 i-Tree Eco

i-Tree Eco is a state-of-the-art, peer-reviewed software suite that provides urban and rural forestry analysis and benefits assessment tools. The software was developed by the USDA Forest Service and numerous co-operators, is in the public domain and is freely accessible.

The i-Tree Eco software employs a series of algorithms into which specific tree parameters are loaded, producing calculated values of a set of out-puts such as biomass, oxygen production, leaf area, carbon storage and sequestration, pollutant removal and avoided runoff. The software also assigns an associated Australian dollar value to the environmental benefits.

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1 The Australian Government Bureau of Meteorology – Adelaide, Waite Institute Station 023031 (adjacent to the Waite Arboretum) which operated 1925 to 1999.

2 An exception to this policy is the historic Elm Avenue. In the years from 2006 - 2015 when rainfall was well below average, inline drip irrigation was applied to maximise the survival and health of the avenue. Supplementary watering ceased after above average rainfall and recovery of the trees in 2016.

The i-Tree Eco Tools help communities of all sizes to strengthen their forest management and advocacy efforts by quantifying the structure of trees and forests, and the environmental services that trees provide. Since the initial release of the i-Tree Eco Tools in August 2006, thousands of communities, non-profit organizations, consultants, volunteers and students have used i-Tree to report on individual trees, stands of trees, neighbourhoods, cities (such as New York and London), and even entire states (www.itreetools.org). This study used i-Tree Eco version 6.1.17 to quantify some of the environmental benefits (also referred to as 'services') of Waite Arboretum trees. The i-Tree Eco software uses standardized field data, preprocessed local hourly meteorological and air pollution concentration data and taxonomic classification to calculate the ecosystem benefits. The software has been adapted for use throughout Australia with many of the necessary species information, location information, and pollution and precipitation data pre-processed and available directly in the i-Tree tools application (https://www.itreetools.org/resources/manuals/Ecov6_ManualsGuides/Ecov6Guide_InternationalProjects.pdf). A detailed account of Model and Field Measurements is given in Appendices 1 & 2.

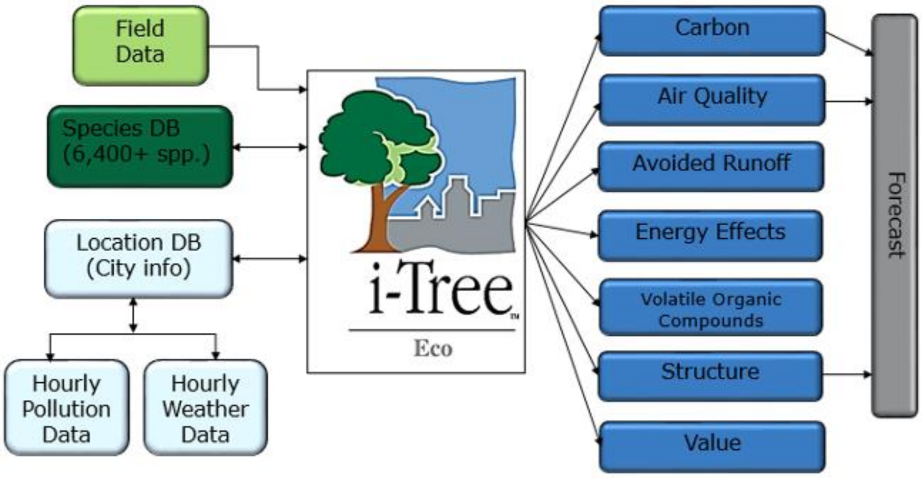


Image Source: https://www.itreetools.org/eco/overview.php

## 1.3 People and trees: providing multiple benefits

In addition to the environmental services delivered by trees and discussed in this report, natural environments, especially trees, are essential elements for liveable cities. There is no doubt that exposure to trees, and green spaces more generally, enhance us psychologically and physiologically (Astell-Burt and Feng 2016). Numerous studies show the multiple health, social cohesion and cognitive benefits provided by trees in the urban environment (Tarran 2009, Pitman and Ely 2013). Benefits include the following:

- Trees play an important role in the provision of shade and reduction of human exposure to solar UV radiation which can cause sunburn, skin cancer and melanoma. Protection by shading is particularly important in children with more sun-sensitive skin. Shade provided by trees varies between species and changes with the season as a result of changing foliage and sun angles. In trials undertaken in the Waite Arboretum to measure the Protection Factor (PF), older, larger trees resulted in higher PFs than those obtained with street trees with lifted canopies. The trees that provided very high levels of protection were Algerian Oak *Quercus canariensis* (PF 51) and English Elm *Ulmus procera* (PF 29) (Gies *et al.* 2007). In parks and school yards where shade is so important, species which are selected for large size, longevity, broad and dense canopy and allowed to spread at low levels provide superior shade.

- Trees cool our cities: heat related deaths are a significant killer of elderly Australians over summer (Moore 2014)

- Surgical patients recover more quickly after operations when they have visual access to trees, requiring shorter stays (Ulrich 1984)

- High levels of greenery in residential environments and along streets are associated with increased physical activity, particularly walking, and reductions in trends towards obesity (Ellaway *et a*l. 2005 and Borst *et al.* 2008)

- Walking in nature results in decreased anxiety, rumination and stress and preservation of positive affect as well as increased cognitive benefits, compared to walking in a treeless urban environment (Bratman *et al*. 2015)

- People in work environments with natural vegetation have greater job satisfaction: a few large trees in their work environment make a substantial difference (Kaplan 2007)

- Daily contact with nature has beneficial effects on blood pressure, heart rate, mood effectiveness and ameliorates stress (Kuo 2001)

- Children who have been moved to greener housing show improved cognitive function (Wells 2000) and contact with nature relieved Attention Deficit Disorder (ADD) and Attention Deficit Hyperactive Disorder (ADHD) (Kuo & Faber Taylor 2004, Faber Taylor & Kuo 2009)

- Apartment housing surrounded by trees and greenery is safer than buildings without trees. Total crime rates reduced by 52% (Kuo & Sullivan 2001a) and there were lower levels of aggression evident (Kuo & Sullivan 2001b)

- A study undertaken in Munich, Germany, found that boys living further than 500 m away from urban green spaces had more behavioural problems compared to those living within 500 m of urban green spaces (Markevych *et al*. 2014).

Urban trees also provide commercial benefits:

- Trees improve economic vitality in terms of market identity, customer preference, and lower vacancy rates (Wolf 2005)

- Trees increase property values (Pandit *et al*. 2013, Plant *et al*. 2015). Based on a house valued at $500,000, Australians would be prepared to pay an extra $35,000 for a house in a green and leafy area, and 34% would be prepared to pay an extra $100,000 (Planet Ark 2014). A tree-lined nature strip added 30% to the value of properties in streets that had trees, compared to similar houses on treeless streets just two streets away (Gonzalez 2007).

With appropriate landscape design, roadside trees can slow driver speeds, protect pedestrians against ‘runaway’ vehicles, reduce stress in drivers and help them focus on the roadway edge. A review of numerous research studies concluded that roadside trees posed no significant extra safety risk (Sanders *et al*, 2012, Bratton and Wolf 2005, Dixon and Wolf, 2007).

Wilson (1984) coined the term ‘biophilia’ meaning a love of nature. The ‘biophilia hypothesis’ stipulates that contact with nature is fundamental to human health because of our innate need to affiliate with living creatures (Ely and Pitman 2012).

In his very influential book the *Last Child in the Woods: Saving our Children from Nature-Deficit Disorder* Richard Louv (2005) described the many benefits to people, especially in childhood development, that frequent connection with nature can provide, and coined the term 'Nature-Deficit Disorder' for a syndrome more common in people deprived of much contact with nature.

Butler (2016) discussed the consequences of a disregard for nature, particularly forests, and its adverse effect on the environment and presented evidence linking disrespect for nature with wider societal issues. He also noted that contact with trees, especially ones that are old, appears to be nourishing psychologically and spiritually. In many traditional societies sacred groves are worshipped and maintained (Ramakrishnan *et al*. 1998).

'Forest bathing', which originated in Japan (shinrin-yoku), is the practice of taking short leisurely walks in a forest for health benefits. Studies in Japan have shown changes in immune markers and stress hormones in people who regularly walk in forests and people with diabetes experienced substantial lowering of blood glucose levels[3].

Waite Arboretum – Angophora Collection – *A. costata, A. floribunda* Photo: J. Gardner

[3] www.japantimes.co.jp/news/2008/05/02/national/forest-therapy-taking-root/

**Figure 1 Aerial image of Waite Campus showing of extent of Waite Arboretum.**

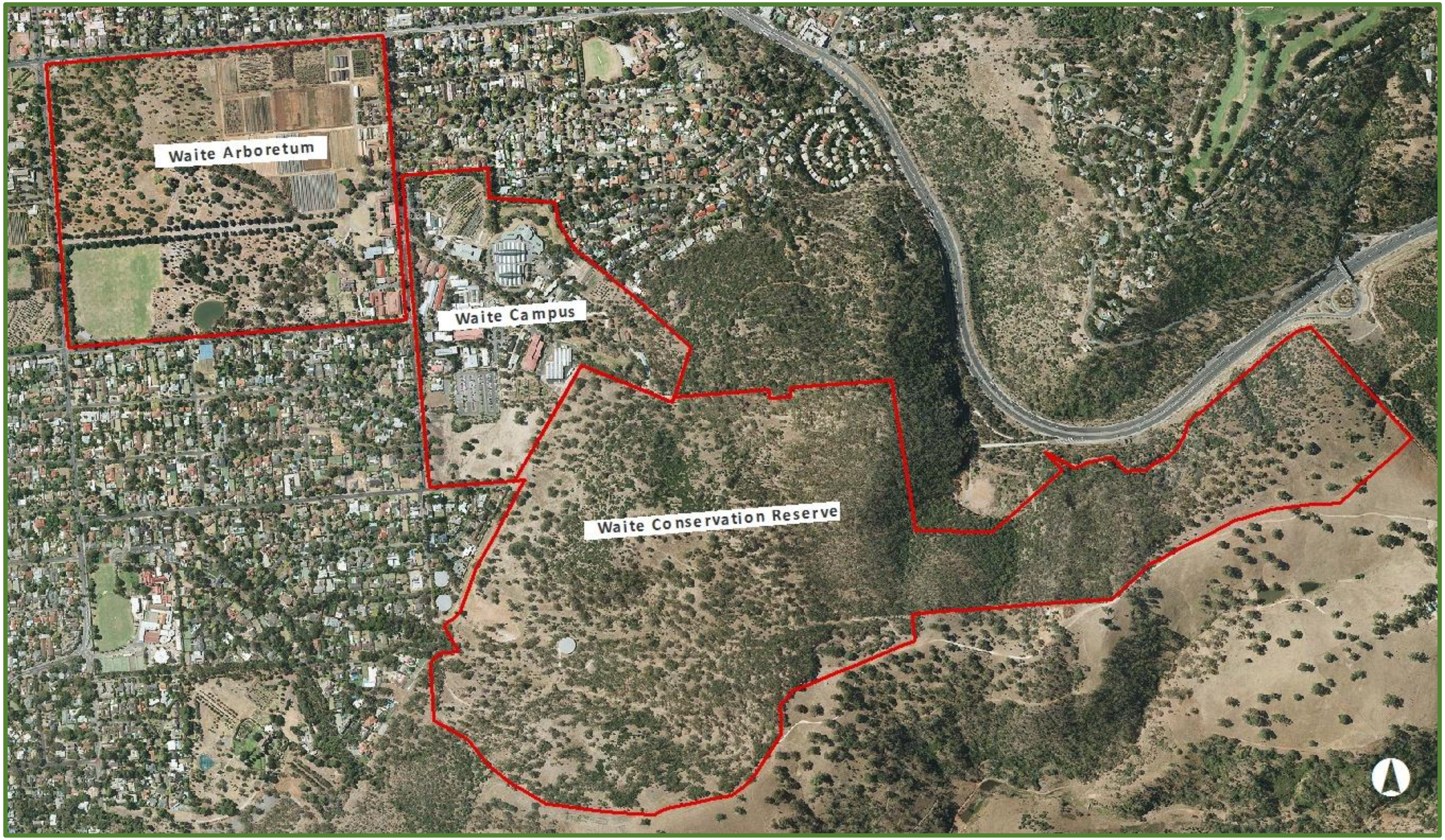

**Figure 2   Aerial image of Waite Arboretum.  Trees included in Survey shown in light green.**

# 2 Approach and Methodology

## 2.1 Data collection and equipment

### 2.1.1 The specimens

The 1,255 trees and shrubs surveyed represent 50% of Arboretum collection (Figure 2). Priority was given to the mature specimens. The specimens not surveyed are more recent plantings or naturally small species.

The calculation of the environmental benefits of each tree was derived by joining two datasets before submitting the field data to i-Tree Eco for analysis. The first dataset was the taxonomic information with the unique Arboretum tree identifiers exported from the Waite Arboretum FileMaker Pro 13 database. The second dataset was the geospatial data ascertained from a 7.5 cm resolution aerial image of the Arboretum (February 2017) procured from Aerometrex and exported into an ESRI ArcGIS 10.4.1 map. Field data was collected using ArcCollector software on a mobile phone or tablet and uploaded in the field to ArcGIS online.

A species code was applied to every specimen, based on i-Tree Eco Species v4.x list. Many species in the Arboretum are uncommon and not in the i-Tree Eco Species list which relies mainly on the US specimen database. In those cases, the closest species match based on size, leaf structure, habit and natural distribution of our species was researched (e.g. eucalypts) or the generic code used. In the few specimens where no generic code was available the specimen was coded as hardwood or softwood. Any species code substitution was noted in our dataset so that the correct code could be incorporated in the future as new codes are published on i-Tree Eco.

### 2.1.2 Field data

Tree measurements and field data were collected for a period of 21 months 2015-2017 by a team of 2 or 3 volunteers led by Erica Boyle. A total of 8 volunteers committed their time to this project.

Field data was gathered on authorized smart phones and tablets equipped with ArcGIS Collector and a paper-based form was manually completed for each tree as a back-up.

Tree data collection included the unique Arboretum tree identifier, species, GPS coordinates, total height, trunk(s) diameter(s) at breast height (DBH), height to crown base, percent crown missing, percent crown dieback and the amount of light exposure the canopy receives from the top and sides. DBH (1.3 m) was measured with a standard forestry DBH tape. All measurements were metric.

i-Tree Eco is capable of interpolating the services with the basic input data of species and DBH measurements, but the quality and accuracy of the results are greatly improved if all of the details recommended by the software are collected.

A dataset of the total height of each specimen was obtained from Aerometrex which used stereophotogrammetry analysis to obtain the data. Where canopies overlapped, the shorter tree height was measured with a Leica Disto ™ D 510 Range Finder Laser Measuring Device, as was the height to crown base.

Canopy percent missing, percent die-back and amount of light received were visually assessed and estimated by the survey team. Field data of deciduous trees were collected during the leaf-on season to properly assess their canopies.

The canopy widths (east-west and north-south) and live height (total height minus percent crown dieback) were calculated in ArcGIS.

The Survey data, formatted to match i-Tree requirements, was loaded into i-Tree Ecosystem software in June 2017. This was then submitted *via* the software to the USDA Forest Service for processing. The analysis was downloaded back into i-Tree software where reports and other information are generated from the analysis.[4]

### 2.1.3 Climate and pollution data

An Australian-compatible version of the i-Tree Eco application was introduced in 2011[5] and stated that all Australian pollution and weather data have been integrated into the Eco application - eliminating the need to acquire local pollution data. Users can select the specific location of the weather station to use during the project setup within i-Tree Eco. The species and field data are integrated with local weather and pollution data to calculate the total environmental services the inventoried trees deliver.

Weather data was sourced from the network of weather stations available from the National Climate Data Centre (www.ncdc.noaa.gov/ ). i-Tree Eco v6.0 states that it has been adapted for use throughout Canada, Australia, and the United Kingdom with the necessary species information, location information, and pollution and precipitation data pre-processed and available directly in the application.

The nearest meteorological station listed with both climate and pollution data was specified as Adelaide Airport (Station number 023034). The Metadata Report of our project was prefaced 'Waite Arboretum Inventory V2, Year: 2017 from i-Tree Eco includes Pollution Details: Year 2011, and Weather Station Details: Year 2011, USAF: 946720, WBAN: 99999. Name: ADELAIDE INTL. (Adelaide International Airport)'.

The Metadata Report indicated that the runoff avoidance was based on an annual rainfall of 120 mm. This is less than 20% of the annual rainfall amount that the Bureau of Meteorology's official ADELAIDE (WAITE INSTITUTE) Station, recorded as a 74 year average, and this discrepancy is discussed in the Results section 3.2.5.

The ground cover between and under trees at the Arboretum is grass and herbaceous broad-leaved weeds and low-growing indigenous species. The introduced groundcovers are gradually being replaced with native grasses, mainly the summer growing native Windmill Grass *Chloris truncata* as well as spear-grasses *Austrostipa* species and wallaby-grasses *Rytidosperma* species. The environmental benefits of the ground cover have not been quantified, although it does contribute to reduced water runoff and is a food source for local butterflies and other wildlife.

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[4] https://www.itreetools.org/eco/overview.php
[5] i-Tree Eco Australia Users Manual v2 (September 2012) A document prepared by ENSPEC for Arboriculture Australia

# 3 i-Tree Ecosystem Analysis: Results[6] and Discussion

## 3.1 Tree characteristics

### 3.1.1 Species diversity and abundance

1,255 trees and shrubs comprising 604 taxa in 146 genera were surveyed in this study representing half the collection of mature trees at the Arboretum. Of the surveyed trees, 509 specimens (40.5% of the surveyed trees) are the eucalypts as *Eucalyptus* spp. (428 specimens in 219 taxa), *Corymbia* spp. (68 in 11 taxa) and *Angophora* spp. (13 in 8 taxa). Six species were planted as avenues and / or perimeter plantings and so are over-represented in the Survey. These are Lemon-scented Gum *Corymbia citriodora* (53 specimens), Sugar Gum *Eucalyptus cladocalyx* (60), English Elm *Ulmus procera* (71), Canary Island Pine *Pinus canariensis* (22), Aleppo Pine *P. halepensis* (15) and Stone Pine *P. pinea* (13) (Figure 3).

Waite Arboretum - view from historic gardens Photo: J. Gardner

Of the trees surveyed, 62% are native to Australia, 17% to Europe, 16% to North and/or South America, 14% to Asia and 5% to Africa. 7% of the species are naturally distributed across more than one continent.

6 i-Tree Ecosystem Analysis Waite Arboretum Inventory June 2017

**Figure 3   Composition of Waite Arboretum Survey trees - 22 genera with the most specimens as percentage of the total.**

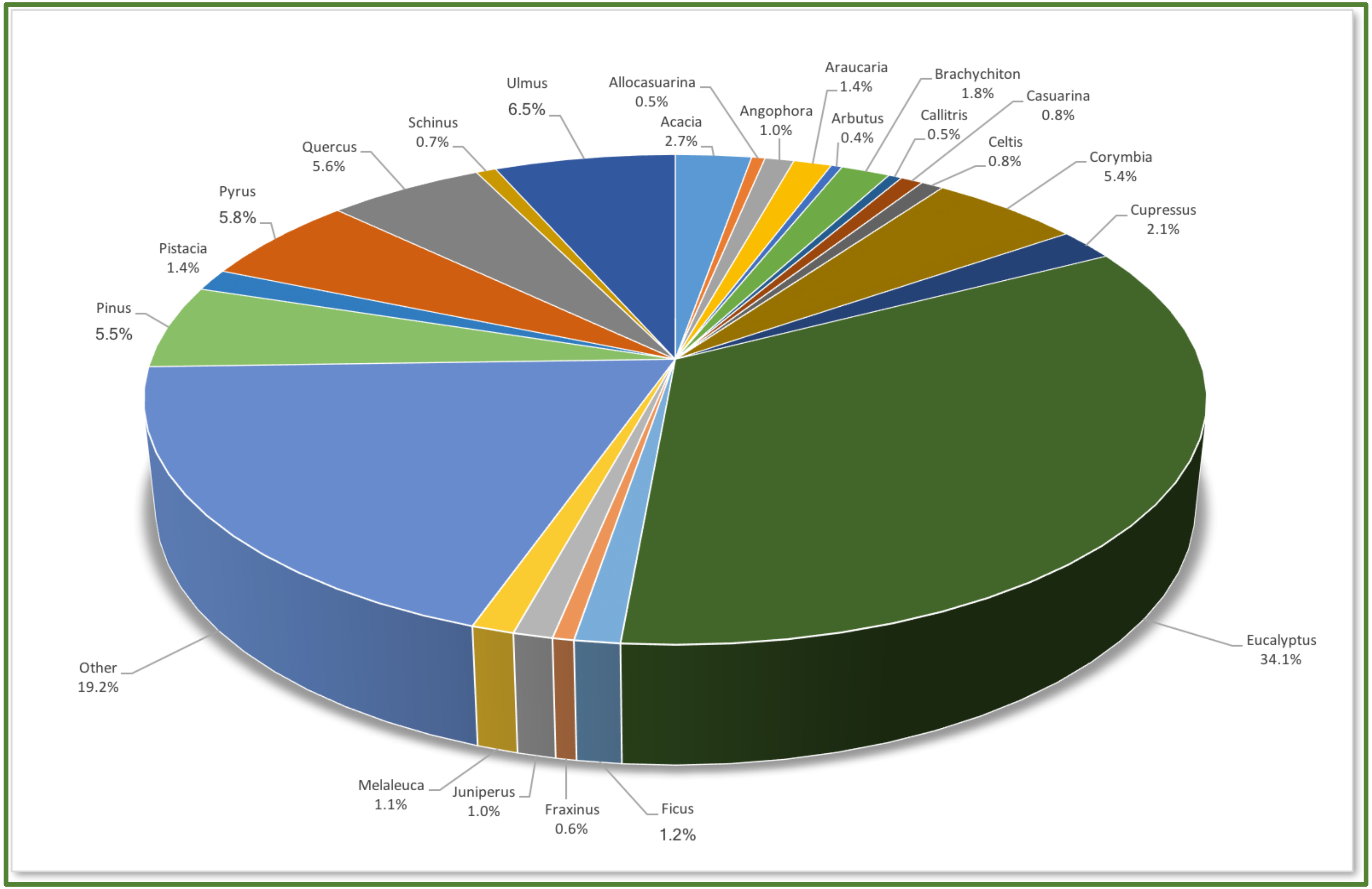


Table 1 summarises the generic composition of all the surveyed trees with the number of species and specimens in each genus

**Table 1 Generic composition of Waite Arboretum Survey trees.**

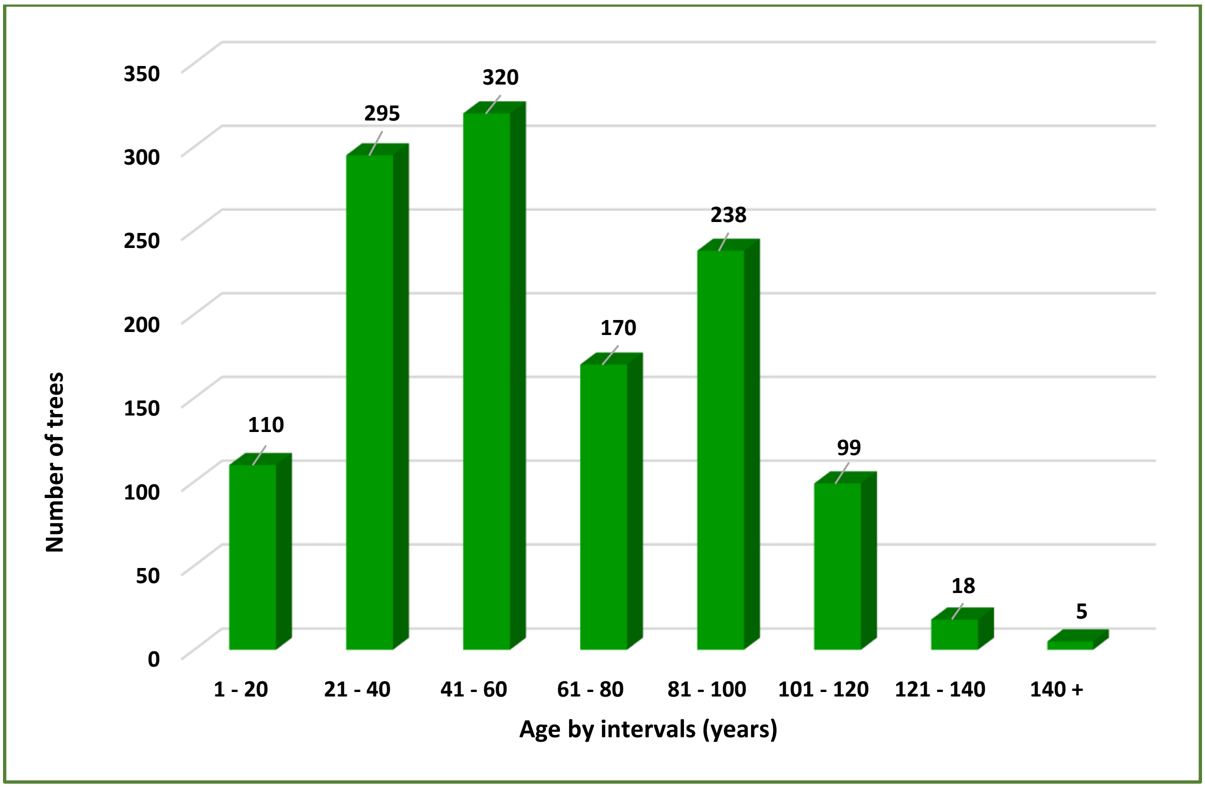
| Genus | No. of taxa | No of specimens |
|---|---|---|
| *Acacia* | 12 | 34 |
| *Acer* | 2 | 2 |
| *Aesculus* | 2 | 5 |
| *Afrocarpus* | 1 | 2 |
| *Agathis* | 1 | 4 |
| *Albizia* | 1 | 1 |
| *Alectryon* | 2 | 5 |
| *Allocasuarina* | 4 | 6 |
| *Alphitonia* | 1 | 1 |
| *Alstonia* | 1 | 1 |
| *Angophora* | 8 | 13 |
| *Araucaria* | 5 | 17 |
| *Arbutus* | 4 | 5 |
| *Arytera* | 1 | 1 |
| *Atalaya* | 1 | 2 |
| *Backhousia* | 1 | 2 |
| *Barklya* | 1 | 1 |
| *Bauhinia* | 1 | 1 |
| *Beilschmiedia* | 1 | 1 |
| *Bolusathanus* | 1 | 2 |
| *Brachychiton* | 8 | 22 |
| *Brahea* | 1 | 1 |
| *Caesalpinia* | 1 | 1 |
| *Callistemon* | 3 | 3 |
| *Callitris* | 4 | 6 |
| *Calocedrus* | 1 | 1 |
| *Calodendrum* | 1 | 3 |
| *Capparis* | 1 | 1 |
| *Carissa* | 1 | 2 |
| *Carya* | 1 | 2 |
| *Casimiroa* | 1 | 1 |
| *Cassia* | 2 | 3 |
| *Castanospermum* | 1 | 1 |
| *Casuarina* | 7 | 10 |
| *Cedrus* | 7 | 17 |
| *Celtis* | 6 | 10 |
| *Ceratonia* | 1 | 2 |
| *Cercis* | 1 | 1 |
| *Citharexylum* | 1 | 1 |
| *Citrus* | 1 | 1 |
| *Clerodendrum* | 1 | 1 |
| *Colliguaja* | 1 | 1 |
| *Corymbia* | 11 | 68 |
| *Crataegus* | 1 | 1 |
| *Cupaniopsis* | 1 | 3 |
| *Cupressus* | 16 | 26 |
| *Curtisia* | 1 | 2 |
| *Cussonia* | 2 | 5 |
| *Diospyros* | 2 | 2 |
| *Dombeya* | 1 | 1 |
| *Dracaena* | 2 | 6 |
| *Dysoxylon* | 1 | 1 |
| *Elaeagnus* | 1 | 1 |
| *Elaeodendron* | 1 | 3 |
| *Enterolobium* | 1 | 1 |
| *Eremophila* | 1 | 1 |
| *Eriobotrya* | 1 | 2 |
| *Eucalyptus* | 219 | 428 |
| *Euclea* | 1 | 2 |
| *Eugenia* | 1 | 3 |
| *Euroschinus* | 1 | 2 |
| *Ficus* | 11 | 15 |
| *Flindersia* | 3 | 6 |
| *Fraxinus* | 5 | 7 |
| *Geijera* | 1 | 3 |
| *Gleditsia* | 4 | 4 |
| *Glochidion* | 1 | 1 |
| *Gmelina* | 1 | 3 |
| *Grevillea* | 1 | 2 |
| *Grewia* | 1 | 1 |
| *Hakea* | 2 | 4 |
| *Harpephyllum* | 1 | 2 |
| *Harpullia* | 1 | 1 |
| *Hymenosporum* | 1 | 1 |
| *Jacaranda* | 1 | 1 |
| *Jacquinia* | 1 | 1 |
| *Jagera* | 1 | 1 |
| *Jubaea* | 1 | 1 |
| *Juglans* | 2 | 2 |
| *Juniperus* | 9 | 13 |
| *Kageneckia* | 1 | 1 |
| *Koelreuteria* | 2 | 3 |
| *Lagerstroemia* | 1 | 1 |
| *Lagunaria* | 1 | 3 |
| *Ligustrum* | 1 | 1 |
| *Lithrea* | 1 | 1 |
| *Lophostemon* | 1 | 2 |
| *Lyonothamnus* | 2 | 3 |
| *Macadamia* | 1 | 1 |
| *Melaleuca* | 12 | 14 |
| *Melia* | 2 | 5 |
| *Mischocarpus* | 1 | 1 |
| *Morus* | 3 | 3 |
| *Myricanthes* | 1 | 1 |
| *Myricaria* | 1 | 1 |
| *Myrsine* | 1 | 1 |
| *Notelaea* | 1 | 2 |
| *Nuxia* | 1 | 1 |
| *Olea* | 1 | 2 |
| *Palinurus* | 1 | 1 |
| *Paulownia* | 1 | 1 |
| *Persea* | 1 | 1 |
| *Phillyrea* | 2 | 2 |
| *Phoenix* | 2 | 2 |
| *Photinia* | 1 | 1 |
| *Phytolacca* | 1 | 2 |
| *Pinus* | 13 | 66 |
| *Pistacia* | 6 | 18 |
| *Pittosporum* | 1 | 1 |
| *Planchonella* | 1 | 1 |
| *Platanus* | 1 | 3 |
| *Platycladus* | 1 | 1 |
| *Pleiogynium* | 1 | 2 |
| *Podocarpus* | 1 | 1 |
| *Polyscias* | 1 | 1 |
| *Pouteria* | 1 | 2 |
| *Pyrus* | 38 | 73 |
| *Quercus* | 41 | 72 |
| *Quillaja* | 2 | 2 |
| *Rhodosphaera* | 1 | 3 |
| *Rhus* | 1 | 1 |
| *Santalum* | 1 | 1 |
| *Schinus* | 5 | 9 |
| *Schotia* | 1 | 2 |
| *Sequoia* | 1 | 1 |
| *Sorbus* | 1 | 1 |
| *Stenocarpus* | 1 | 3 |
| *Sterculia* | 1 | 1 |
| *Styrax* | 1 | 1 |
| *Syzygium* | 1 | 6 |
| *Tamarix* | 2 | 3 |
| *Tarchonanthus* | 1 | 1 |
| *Tetraclinis* | 1 | 1 |
| *Thuja* | 1 | 1 |
| *Tipuana* | 1 | 1 |
| *Toona* | 1 | 1 |
| *Ulmus* | 5 | 81 |
| *Umbellularia* | 1 | 2 |
| *Ungnadia* | 1 | 1 |
| *Vauquelinia* | 1 | 1 |
| *Vepris* | 1 | 1 |
| *Washingtonia* | 1 | 1 |
| *Yucca* | 1 | 1 |
| *Zelkova* | 2 | 3 |
| *Ziziphus* | 1 | 1 |

### 3.1.2 Tree age and size

There are five remnant Grey Box *Eucalyptus microcarpa* trees which are thought to predate European settlement in 1836. The earliest planting by European settlers, in 1877, is the avenue of Sugar Gums *Eucalyptus cladocalyx* lining the sweeping driveway to Waite's residence. Only 13 of these trees remain with those at the eastern end being replaced by Lemon-scented Gums *Corymbia citriodora* planted c1960. Other early plantings include a Bunya Pine *Araucaria bidwillii* and a Canary Island Pine *Pinus canariensis* planted by Waite in 1893 adjacent to his residence. The perimeter plantings are thought to date c1900. Elm Avenue *Ulmus procera* was planted in 1928 when the Arboretum was established, and frames a vista from the main Waite Institute building to the sea.

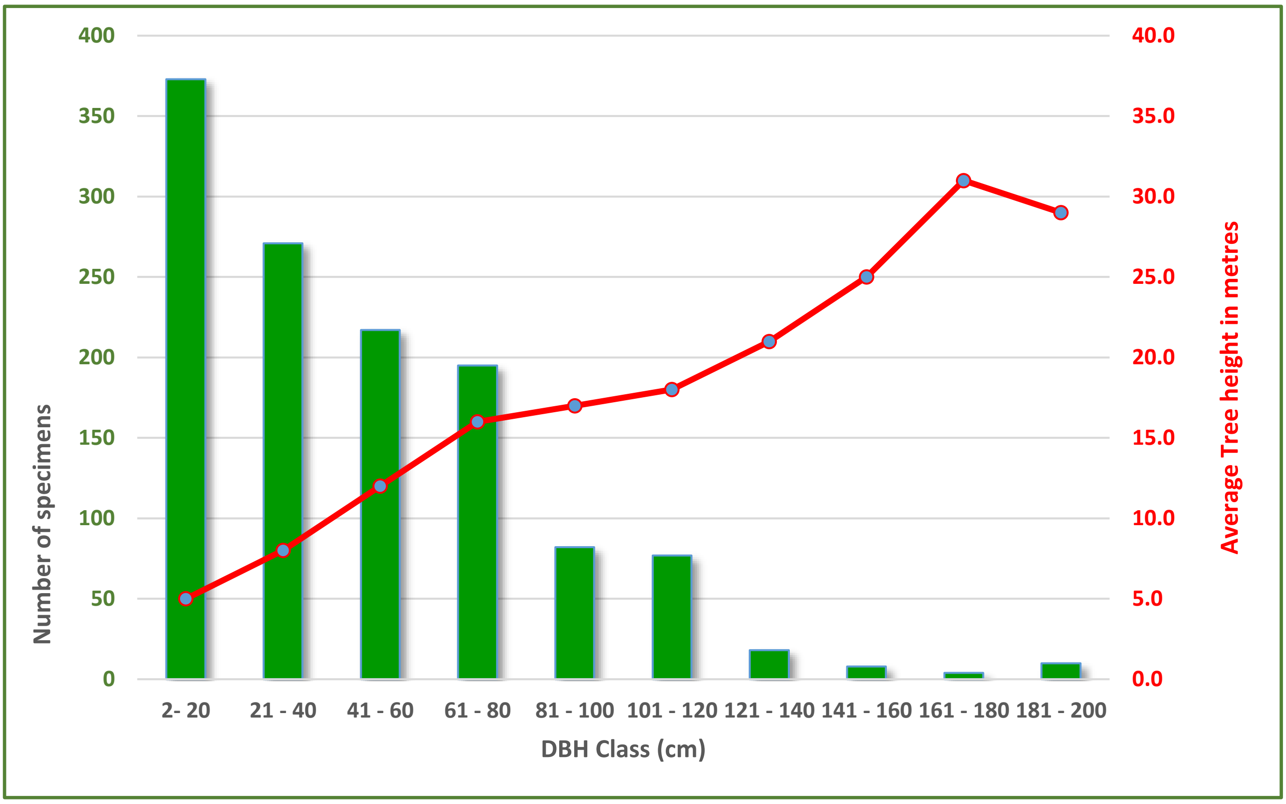
About 1,000 trees were planted in the first two years of the Arboretum, with many replicate specimens. Planting is ongoing as trees senesce or common replicates are removed to make way for species more suitable to the climate, of interest for their rarity or for research purposes. Trees less than 20 years old are under-represented in the age class statistics as the Survey focussed on larger, established specimens Figure 4).

**Figure 4 Composition of Waite Arboretum Survey trees by age class.**




Field measurements of size included height, canopy extent and trunk diameter at breast height (DBH) at 1.3 m. In the Survey of Waite Arboretum trees the DBH class with the greatest number of trees was 2-20 cm with 373 individuals (30% of the total). The average height increases with DBH class with the exception of 181-200 cm class (Figure 5). Very large trees (with DBH greater than 1 metre) numbering 117 individuals comprise 9% of the total surveyed. Of the tallest 20 specimens 15 are Sugar Gums *Eucalyptus cladocalyx*, the remainder are Canary Island Pine *Pinus canariensis* and Aleppo Pine *P. halepensis*. The tallest specimen in this Survey is a Sugar Gum with a height of 37 m.

**Figure 5 Composition of Waite Arboretum Survey trees by DBH class with corresponding average tree height.**




Generally, the trees with the greatest DBH have correspondingly greater canopy extent but the relationship is not exact because of the different habits of different species (Figure 6).

Larger trees tend to offer more functional services due to the greater amount of tissue available to store and sequester carbon, and the generally larger leaf surface area able to remove pollution and intercept rainfall (Seed Consulting, 2016).

Hollows provide habitat for many native animals. It can take more than 80 years for natural hollows to develop in Australian trees, and so clearance of older and remnant vegetation has led to a missing piece of habitat. Bird species such as rosellas, lorikeets, pardalotes and kookaburras are just a few of the native birds that rely on hollows for breeding[7]. It is therefore important that mature trees are retained and kept as healthy as possible to gain maximum benefits and support richer biodiversity.

As stated by Dwyer *et al*. 2003: "The important contributions of large trees include aesthetics, purifying the air, retaining rainfall, providing shade, and providing symbolic community heritage values. In fact, it is the enduring nature of large trees in a rapidly changing urban environment that contributes to their high symbolic values and a sense of permanence in our fast-changing society".

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[7] "*Encouraging Native Birds*" Fact sheet – Backyards 4 Wildlife series, Government of South Australia, Natural Resources, Adelaide and Mt Lofty Ranges. 2016

**Figure 6 Aerial image of Waite Arboretum Survey trees showing the location of trees of different DBH classes –** Symbology displays graduated colour ramp from smallest (lightest shade) to largest trunk diameter (darkest shade).

### 3.1.3 Canopy cover and leaf area

Many tree benefits correlate directly to the healthy leaf surface area of the plant.

Leaf area of trees was assessed using:

- Species – to identify shade coefficient
- Total height – to estimate height of the crown
- Crown base height – to estimate height of the canopy
- Crown width – to identify crown width dimension
- Percent crown missing – to modify base leaf area for actual amount present[8].

Leaf biomass is based on leaf area estimates and uses the same direct measures (as described above).

Leaf Area Index (LAI) is a widely used descriptive variable and represents the photosynthetic functionality and transpirational surface of vegetation. LAI is used in calculation of crop production in forestry and agronomy, climate modelling, groundwater interception and other studies. LAI can be defined in several ways:

- One-sided green leaf area per unit ground surface area in broadleaf communities[9].
- Half the total outside area, not the projected area (Gonsamo and Pellikka 2008), in order to avoid leaf shape dependency of LAI.
- i-Tree Eco analysis calculates LAI as Leaf Area ($m^2$) / Canopy Area ($m^2$)

LAI can be determined non-destructively by:

- Gap Fraction Method – the gap fraction (the amount of visible sky from beneath the canopy) can be used to calculate the amount of foliage (assuming the random position of leaves within the canopy)[10]
- Hemispherical Photography[11]
- Photosynthetically Active Radiation (PAR) Inversion – integrated reflectance model combining radiative transfer and geometric optical properties to obtain inverse LAI
- Spectral Reflectance - Remote sensing data - atmospherically corrected Normalised Difference Vegetation Index (NDVI) is used as a proxy for LAI.

The surveyed trees cover 79% of the Waite Arboretum area and provide 77 hectares of leaf area. The overall density of surveyed trees (50% of the total collection) is 46 trees per hectare. In terms of contribution to the total leaf area the three dominant species are *Eucalyptus cladocalyx* (13.5%), *Ulmus procera* (11.9%) and *Corymbia citriodora* (9.3%). These species have the largest number of individuals in the Survey. The combined eucalypts (*Eucalyptus*, *Corymbia* and *Angophora*) totalling 509 individuals comprise 40.5% of the surveyed population and account for 47.8% of the total leaf area.

The Waite Arboretum Survey included detailed measurements for all 1,255 specimens which were used in the i-Tree Eco analysis to determine the Leaf Area and LAI. Table 2 lists the top 40 specimens selected by the highest leaf area, and includes canopy area, leaf area index and leaf biomass.

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[8] Use of Direct Measures by i-Tree Eco (v6.0)
[9] https://en.wikipedia.org/wiki/Leaf_area_index accessed 24/7/17
[10] Measuring Leaf Area Index (Oct. 5, 2015) https://www.youtube.com/watch?v=t0KOc_tgjT8 accessed 11/08/17
[11] Canopy 101:Leaf Area Index – Theory, Measurement and Application Steve Garrity (Feb, 17, 2015) https://www.youtube.com/watch?v=GurnDQ8m1Zkt=1507s (accessed 11/08/17)

**Table 2 Top 40 specimens selected by highest leaf area, including canopy area, leaf area index and leaf biomass.**

| Arb. Tree ID | Scientific name | Common name | Leaf Area (m²) | Canopy Area (m²) | Leaf Area Index | Leaf Biomass (g/m²) |
|---|---|---|---|---|---|---|
| 1201G | *Eucalyptus cladocalyx* | Sugar Gum | 4,586 | 891.4 | 5.1 | 594 |
| 1201D | *Eucalyptus cladocalyx* | Sugar Gum | 4,222 | 1,168.7 | 3.6 | 547 |
| 2153 | *Eucalyptus cladocalyx* | Sugar Gum | 3,606 | 843.6 | 4.3 | 467 |
| 1880 | *Araucaria bidwillii* | Bunya Pine | 3,530 | 400.6 | 8.8 | 553 |
| 1201J | *Eucalyptus cladocalyx* | Sugar Gum | 3,383 | 717.7 | 4.7 | 438 |
| 2144A | *Pinus canariensis* | Canary Islands Pine | 3,371 | 759.8 | 4.4 | 325 |
| 1201K | *Eucalyptus cladocalyx* | Sugar Gum | 3,290 | 742.6 | 4.4 | 426 |
| 41 | *Eucalyptus cladocalyx* | Sugar Gum | 3,229 | 686.3 | 4.7 | 418 |
| 1201L | *Eucalyptus cladocalyx* | Sugar Gum | 3,211 | 623.5 | 5.1 | 416 |
| 1201M | *Eucalyptus cladocalyx* | Sugar Gum | 3,072 | 706.2 | 4.3 | 398 |
| 1201E | *Eucalyptus cladocalyx* | Sugar Gum | 3,039 | 688.0 | 4.4 | 393 |
| 2100 | *Eucalyptus cladocalyx* | Sugar Gum | 3,004 | 542.5 | 5.5 | 389 |
| 1201F | *Eucalyptus cladocalyx* | Sugar Gum | 2,938 | 590.5 | 4.9 | 380 |
| 1201A | *Eucalyptus cladocalyx* | Sugar Gum | 2,797 | 632.6 | 4.4 | 362 |
| 1A | *Pinus canariensis* | Canary Islands Pine | 2,709 | 498.6 | 5.4 | 261 |
| 37 | *Corymbia citriodora* | Lemon-scented Gum | 2,687 | 769.1 | 3.5 | 201 |
| 2150D | *Eucalyptus cladocalyx* | Sugar Gum | 2,672 | 657.7 | 3.5 | 346 |
| 1201C | *Eucalyptus cladocalyx* | Sugar Gum | 2,666 | 675.8 | 3.9 | 345 |
| 2149 | *Eucalyptus cladocalyx* | Sugar Gum | 2,654 | 679.0 | 3.9 | 344 |
| 21 | *Eucalyptus microcarpa* | Grey Box | 2,619 | 646.5 | 4.0 | 339 |
| 1201B | *Eucalyptus cladocalyx* | Sugar Gum | 2,609 | 533.2 | 4.9 | 338 |
| 1522 | *Eucalyptus microcarpa* | Grey Box | 2,546 | 629.1 | 4.0 | 330 |
| 2118 | *Pinus canariensis* | Canary Island Pine | 2,544 | 495.8 | 5.1 | 245 |
| 2114 | *Pinus canariensis* | Canary Island Pine | 2,478 | 457.2 | 5.4 | 239 |
| 2110 | *Pinus halepensis* | Aleppo Pine, Jerusalem Pine | 2,433 | 673.1 | 3.6 | 235 |
| 1562 | *Corymbia variegata* | | 2,426 | 568.7 | 4.3 | 182 |
| 2144D | *Platanus x acerifolia* | London plane | 2,386 | 518.0 | 4.6 | 110 |
| 2152 | *Eucalyptus cladocalyx* | Sugar Gum | 2,333 | 443.1 | 5.2 | 302 |
| 2150L | *Eucalyptus cladocalyx* | Sugar Gum | 2,311 | 441.2 | 5.2 | 299 |
| 2143E | *Eucalyptus cladocalyx* | Sugar Gum | 2,299 | 473.3 | 4.9 | 298 |
| 948 | *Ficus rubiginosa* | Port Jackson Fig, Rusty Fig | 2,284 | 565.7 | 4.0 | 171 |
| 101 | *Eucalyptus cladocalyx* | Sugar Gum | 2,220 | 718.2 | 3.1 | 287 |
| 1637 | *Eucalyptus dawsonii* | Slaty Gum | 2,219 | 449.6 | 4.9 | 287 |
| 2124 | *Pinus pinea* | Stone Pine | 2,142 | 458.3 | 4.7 | 206 |
| 2106 | *Pinus canariensis* | Canary Island Pine | 2,141 | 394.0 | 5.4 | 206 |
| 2140 | *Pinus pinea* | Stone Pine | 2,135 | 610.1 | 3.5 | 206 |
| 3248 | *Corymbia citriodora* | Lemon-scented Gum | 2,109 | 425.0 | 4.9 | 158 |
| 2144B | *Eucalyptus camaldulensis* | River Red Gum | 2,078 | 485.7 | 4.3 | 288 |
| 2153A | *Eucalyptus cladocalyx* | Sugar Gum | 2,039 | 563.8 | 3.6 | 264 |
| 1617 | *Eucalyptus sideroxylon* | Mugga, Red Ironbark | 1,985 | 401.9 | 4.9 | 272 |

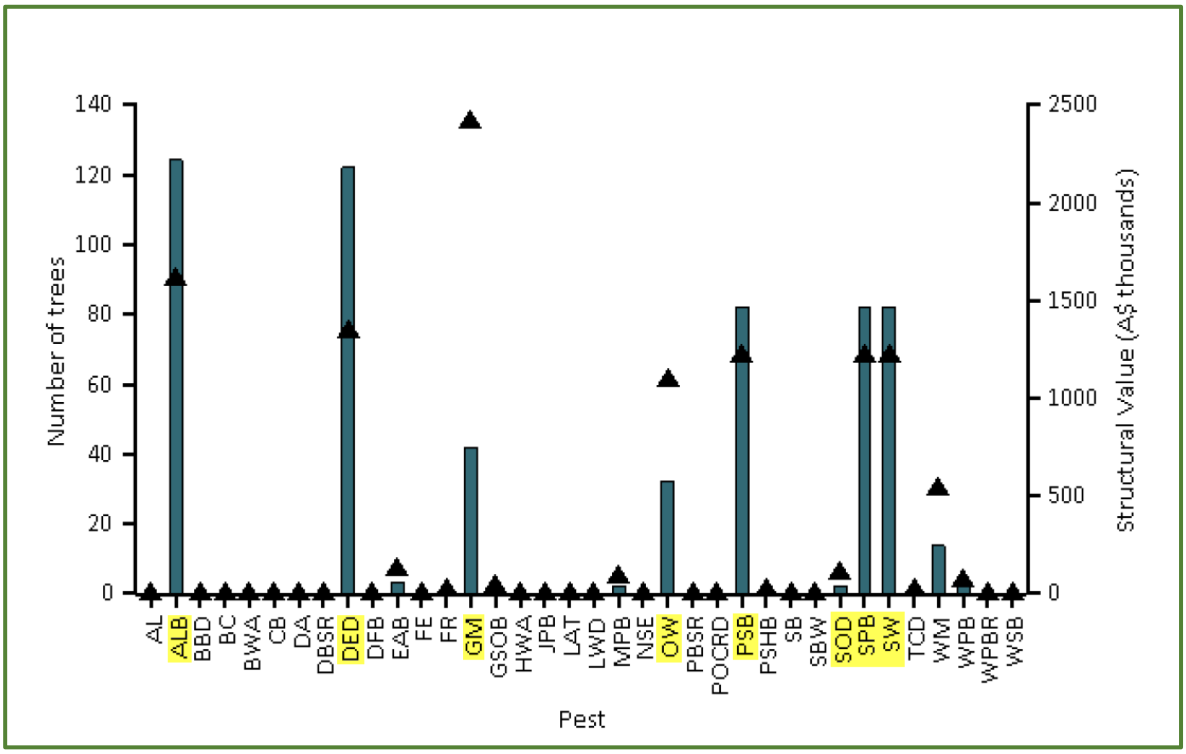
## 3.1.4 Tree health and potential pests

The i-Tree Eco Report assigns a condition value of Excellent, Good, Fair or Poor to each tree. The assessment is based solely on the % crown dieback (www.itreetools.org). On this criterion, the health of the surveyed trees was assessed as Excellent (70%), Good (28%) and Fair (2%).

There are many threats to Australia's Urban Forests from a combination of native and established introduced insects and pathogens (together defined as pests), and overseas incursions (Smith and Smith, 2014). The pests reduce the health of the trees and potentially cause death, adversely affect biodiversity values and cause significant damage in parks and gardens. The main strategy against pests in the Arboretum is to maintain the trees in good health by mulching and weed control. The use of insecticides in the Waite Arboretum is limited to trunk injection in the avenue of elms.

The i-Tree Eco Waite Arboretum Survey analysed 36 pests and pathogens for their potential impact on the trees should the pests become established in Australia (Figure 7). Of these 36 pests, eight (highlighted) were calculated to potentially impact 30 or more specimens in the Arboretum with an associated compensatory cost of A$500,000 to A$2.2 million. The highlighted pests are described below, as well as other pests such as Fire Blight, Giant Pine Scale and Myrtle Rust which are not considered in i-Tree Analysis but are judged by the Australian Government biosecurity agencies to be a potential or actual risk. Elm Leaf Beetle is also included in this report as the pest is already present in the Waite Arboretum and is well established in Australian cities.

**Figure 7 Number of trees at risk (points) from potential pests and pathogens and associated compensatory value (bars)** Source: "i-Tree Eco Waite Arboretum Inventory June 2017"



**Asian Gypsy Moth** *Lymantria dispar* (GM) is one of the top 40 national priority plant pests that are exotic to Australia and are under eradication or have limited distribution. These are the focus of government investment and action. Asian Gypsy Moth occurs throughout temperate Asia, Russia, China, and Korea and can feed on the leaves of over 600 species. Each larva consumes about $1m^2$ of leaves in its lifetime. The pest has spread to Europe, the Middle East, Africa, North America and New Zealand. Eradication campaigns have occurred in the USA and New Zealand at great financial cost.[12] The i-Tree Eco Waite Arboretum Survey indicates that should this pest become established in Australia it would threaten 10.8 % of the surveyed population, which represents a potential loss of A$752,000 in Structural Value.

**Asian Longhorn Beetle** *Anoplophora glabripennis* (ALB) is a major risk. It is an invasive forest pest with no natural enemies in Australia. The beetle attacks nearly all broadleaf trees with elms and plane trees among the preferred hosts. Asian Longhorn Beetle which is native to China, Japan and Korea is not established in Australia, but border interceptions have occurred. The highest risk is on imported timber, wood pallets, furniture and other such items, and all timber products from Asia must be treated before being imported or on arrival in Australia. Asian Longhorn Beetle could potentially damage our forest, natural environment, gardens and street trees[13]. The i-Tree Eco Waite Arboretum Survey indicates that ALB poses a potential threat to 7.2% of the trees surveyed, which represents a potential loss of A$2.22 million in Structural Value.

**Dutch Elm Disease** (DED) is caused by fungus *Ophiostoma ulmi* which causes vascular wilt and is fatal. It is estimated to have killed >17 million of 23 million elms in southern England[14] and in the United States it has killed over 50% of the native elm population since it was first reported in the 1930s. Elm bark beetles transport, and root connections / grafts transmit, the fungal spores into healthy elms to initiate new DED infections. The European Elm Bark Beetle *Scolytus multistriatus* is an important vector of the disease overseas. This vector is not yet present in Australia, however there are native bark beetles which can act as vectors. DED has not reached Australia although it is as close as New Zealand. DED was one of the USA 40 National priority plant pests in 2016. An Australian National DED contingency plan has been developed and includes pre-introduction measures to reduce the impact of the pathogen should it be introduced (Smith and Smith, 2014). The i-Tree Waite Arboretum Inventory indicates the Arboretum could possibly lose 6% of the surveyed trees to this pest worth A$2.18 million in Structural Value.

**Elm Leaf Beetle** *Xanthogaleruca luteola* (ELB) is an important pest of elm trees. It exists in Europe and was introduced into the United States around 1834. ELB was first discovered in Australia in 1989 in Victoria, then in Tasmania - Launceston in 2002 and Hobart in 2008. The first record in South Australia was 2011 and soon after a light infestation was found in the Waite Arboretum. ELB is now well established in these Australian cities. ELB larvae skeletonise the leaves and the adults chew shot holes in the leaves. Severe infestations weaken mature trees and reduce their aesthetic and amenity value. Elms subjected to repeated ELB attack are more susceptible to other pests and disease. Although a single, heavy infestation of ELB can completely defoliate an elm, the tree will send out new leaves in the next season. If ELB is not controlled the growth of the tree will be affected and the tree may eventually die after a few years[15].

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[12] http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0013/443110/Exotic-Pest-Alert-Asian-gypsy-moth.pdf Jan. 2017

[13] http://www.agriculture.gov.au/SiteCollectionDocuments/longhorn-beetle.pdf May 2016

[14] http://www.agriculture.gov.au/pests-diseases-weeds/forestry-timber#field-guide-to-exotic-pests-and-diseases-dutch-elm-disease accessed 14/8/17.

[15] http://dpipwe.tas.gov.au/Documents/Elm_leaf_beetle_fact_sheet.pdf May 2013

The 70 English Elms in the Waite Arboretum Elm Avenue planted in 1928 - 1929 form an impressive landscape element. In 2015 the elms were treated for ELB with trunk injection with Imidacloprid which is considered to be the most effective and environmentally sound option. The health of the elms was promoted by summer watering during the drought years, mulching and weed control. To date the infestations have been light with little appreciable damage. The five Chinese Elms *Ulmus parvifolia* in the Arboretum are unaffected.

**Fire Blight** *Erwinia amylovora* (FB), one of the top national priority plant pests, is a devastating bacterial disease that mainly infects apple and pear trees. Currently, there are no effective chemical controls available where this pest is present. It is a major problem in Europe, Asia, USA and New Zealand[16]. Waite Arboretum has 95 pear trees representing 23 species, some of them very rare such as *Pyrus tadshikistanica* and *P. korshinskyi.* All could be at potential risk from Fire Blight.

**Giant Pine Scale** *Marchalina hellenica* (GPS) is a scale insect that is native to the eastern Mediterranean region, mainly Greece and Turkey. It sucks the sap of pine trees, mainly the Turkish Pine *Pinus brutia*, and to a lesser extent Aleppo Pine *Pinus halepensis* and Stone Pine *Pinus pinea*. The Waite Arboretum has 77 pine trees representing 14 species including 31 Turkish, Aleppo and Stone Pines. This pest has recently been found in metropolitan Adelaide and in Victoria on Aleppo Pines and on Monterey Pines *Pinus radiata*.[17]

**Japanese Sawyer Beetle** *Monochamus alternatus* (JSB) is one of a number of pine-infesting longhorn beetles that attack stressed or recently felled trees as well as cedar, spruce and fir. The main concern is that JSB, like other *Monochamus* species, is a vector for the pine wilt nematode *Bursaphelenchus xylophilus* which is native to North America. The pests have not yet been recorded in Australia, but are most likely to arrive in imported timber and wood used for pallets from Asia where the nematode has been introduced (Smith and Smith, 2014). JSB was one of the USA 40 National priority plant pests in 2016.

**Myrtle Rust** *Puccinia psidii* (MR) first described on guava in Brazil, is a fungus which causes leaf and shoot death on Myrtaceae species. Repeated infection may result in loss of vigour and death. It is widely distributed in native forests along the east coast of Australia where the host range has expanded rapidly to over 240 species (Smith and Smith, 2014). Incursion into Victoria occurred through transport of nursery plants where it is currently under containment. It has not yet been recorded in South Australia. Infection by Myrtle Rust requires conditions of high relative humidity so spread is restricted by climate and poses more of a risk to nurseries than the Waite Arboretum collection.

**Oak Wilt** (OW) is a devastating disease caused by the fungus *Ceratocystis fagacearum* and can kill trees in a single season. The origin of the pathogen is not known but recent evidence suggests that the pathogen was introduced into the United States from Central or South America or from Mexico[18]. It is not yet in Australia. The i-Tree Eco Waite Arboretum Survey indicates that OW poses a potential threat to 4.9% of the surveyed trees, which would represent a loss of A$577,000 in Structural Value.

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[16] http://www.planthealthaustralia.com.au/wp-content/uploads/2013/03/Fire-blight-FS.pdf Jan. 2014
[17] http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/542365/Exotic-Pest-Alert-Giant-pine-scale.pdf Feb.2017
[18] https://en.wikipedia.org/wiki/Oak_wilt accessed 14/8/17

**Pine Shoot Beetle** *Tomicus piniperda* (PSB) is a bark beetle native throughout Europe, northwestern Africa, and northern Asia. It is one of the most destructive shoot-feeding species in northern Europe. Its primary host plant is Scots Pine *Pinus sylvestris*, but it also attacks European Black Pine *P. nigra* and other pine species.[19] The i-Tree Eco Waite Arboretum Survey indicates that PSB has the potential to affect 5.4% of the surveyed trees with a A$1.47 million structural value.

**Sirex Woodwasp** *Sirex noctilio* (SW) attacks pine trees and can devastate pine plantations. Originally from Europe, *Sirex* was first detected in Australia in 1952 in Tasmania, and has since spread to Victoria, then west to South Australia and north as far as the Queensland border, despite early intensive eradication attempts. Effective biological control measures have been introduced and these currently maintain *Sirex* at low levels across much of Australia. The most effective biological control agent is an introduced nematode (*Beddingia siricidicola*) which sterilizes female wasps. A number of parasitic wasps have also been introduced, of which *Ibalia leucospoides* is the most common. Importantly, annual re-introductions of the nematode into forests is required to ensure effective ongoing *Sirex* suppression. This program is internationally recognised as a biological control success story.[20] The i-Tree Eco Waite Arboretum Survey indicates that *Sirex* poses a threat to 5.4% of the surveyed species, which represents a potential loss of A$1.47 million in Structural Value.

**Southern Pine Beetle** *Dendroctonus frontalis* (SPB) is the most destructive insect pest of pine in southern United States. It occurs in North, Central and South America[21]. The i-Tree Eco Waite Arboretum Survey indicates this pest would threaten 5.4% of the population, with the potential loss of A$1.47 million in Structural Value.

**Sudden Oak Death** (SOD) is caused by the oomycete plant pathogen *Phytophthora ramorum*. The disease kills oaks and other species of trees and has had devastating effects in California and Oregon. It is also present in Europe. Other species in the Waite Arboretum that are susceptible to SOD include Madrone *Arbutus menziesii*, California Bay Laurel *Umbellularia calilfornica*, Californian Buckeye *Aesculus californica* and Big Leaf Maple *Acer macrophyllum*[22]. The i-Tree Eco Waite Arboretum Survey indicates the potential loss from SOD is 0.5% of the surveyed trees with a Structural Value of A$41,800.

## 3.2 Ecosystem Services

### 3.2.1 Air pollution removal

Air pollution is the world's largest single environmental health risk, with 3.7 million deaths every year attributable to outdoor air pollution (World Health Organisation 2015)[23]. Common sources of outdoor air pollutants include motor vehicles and other transport, industrial facilities, power production and forest fires.

Air pollutants of major public health risk include carbon monoxide (CO), ozone ($O_3$), nitrogen dioxide ($NO_2$), sulphur dioxide ($SO_2$) and particulate matter. Particulate matter with a diameter less than 2.5 microns ($PM_{2.5}$) is of most concern. Epidemiological studies confirm its causal link to cardiovascular mortality and morbidity, respiratory disease and other adverse health outcomes (REVIHAAP 2013).

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19 https://en.wikipedia.org/wiki/Tomicus_piniperda accessed 14/8/17
20 http://australiansirex.com.au accessed 14/8/17
21 http://entnemdept.ufl.edu/creatures/trees/southern_pine_beetle.htm accessed 14/8/17
22 https://en.wikipedia.org/wiki/Phytophthora_ramorum accessed 14/8/17
23 http://who.int/mediacentre/news/releases/2015/wha-26-may-2015/en/

Ozone is a powerful oxidant that can cause muscle contraction in the airways, reducing the volume of air that can be inhaled and causing shortness of breath and damage to lung tissue. It also increases the permeability of lung cells rendering them more susceptible to toxins and microorganisms. Children breathe more rapidly than adults and inhale more pollution per kilogram of body weight and it is suggested that this then puts children at greater risk from exposure to ozone[24]. Ozone exposure also reduces the overall productivity of plants, damaging cells and leaf tissue. This reduces the photosynthetic ability and weakens the plants making them more susceptible to disease, pests, cold and drought[25].

In addition to health risk, poor air quality can also damage landscape infrastructure and ecosystem processes. Ozone can cause substantial damage to a range of man-made materials and products (both the functional and aesthetic qualities) resulting in significant economic losses as a result of increased cost of maintenance, upkeep and replacement.

Ozone in the upper atmosphere (stratospheric ozone) reduces the amount of ultraviolet light entering the Earth's atmosphere protecting plant and animal life from this harmful radiation. However exposure to ozone at ground level is very harmful to human health and this is reflected in the high value of its removal of A$4,105 / year.

According to the iTree Eco analysis the surveyed trees of the Waite Arboretum remove up to 679 kgs of ozone per year, more than half of the total pollution removal by the surveyed trees (Figure 8).

Trees improve air quality by directly removing pollutants from the air and reducing the temperature, but also indirectly by shading our buildings and reducing air-conditioning use and thus reducing the emissions from power sources.

Trees are particularly effective at reducing levels of particulate matter (Butler 2016). Trees remove $PM_{2.5}$ when it is deposited on leaf surfaces, but the pollutant can be re-suspended to the atmosphere, especially in dry months, or be removed during rain events and transferred to the soil. The i-Tree Eco model incorporates a 50% re-suspension rate of particles (Appendix 1).

In the i-Tree Eco analysis, pollution removal is calculated for $O_3$, $SO_2$, $NO_2$ and $PM_{2.5}$. Air pollution removal estimates are derived from calculated hourly tree-canopy resistances for $O_3$, $SO_2$ and $NO_2$. The removal of CO and $PM_{2.5}$ were based on measured values from the literature that were adjusted depending on leaf phenology and leaf area (Appendix 2).

Pollution removal by the Waite Arboretum surveyed trees was greatest for ozone (679 kg/yr) followed by nitrogen dioxide (502 kg/yr), with $PM_{2.5}$, $SO_2$ and CO in much smaller amounts (Figure 8).

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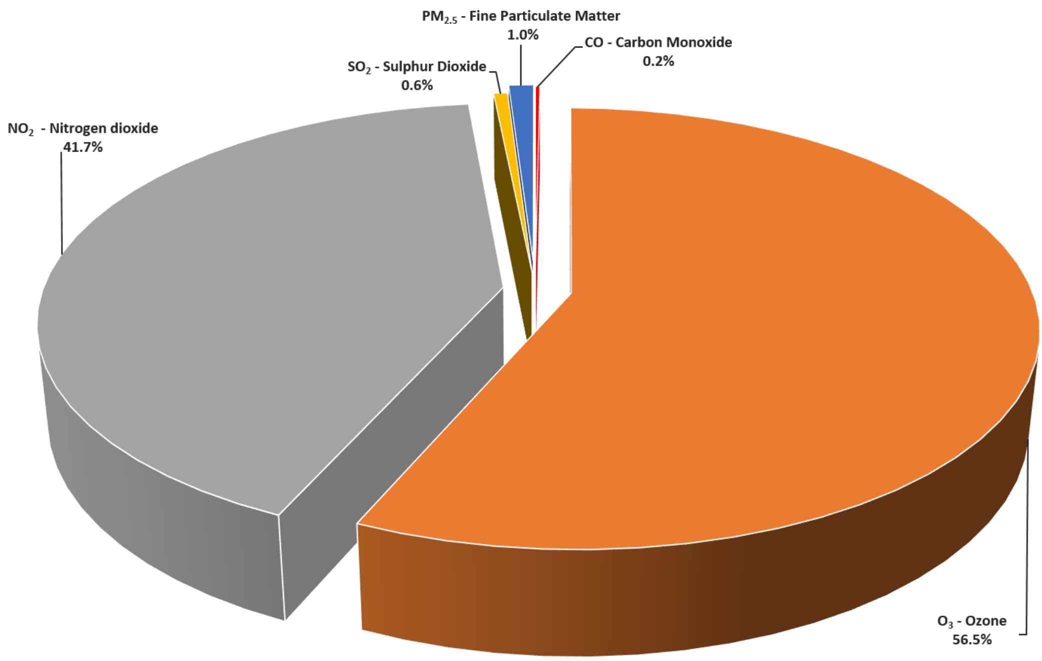
[24] www.epa.gov/ozone-pollution/health-effects-ozone-pollution

[25] www.arb.ca.gov/research/aaqs/caaqs/ozone/ozone-fs.pdf

**Figure 8 Waite Arboretum Survey - Pollutants removed as a percentage of the total.**




The amount of removal of each pollutant and the corresponding $A value / year is summarized in Table 3 and illustrated in Figure 9. The very high value of A$142,612 per tonne of $PM_{2.5}$ removal reflects the high cost to human health of this pollutant. In total it was estimated that the trees removed 1.2 tonnes of air pollution (CO, $O_3$, $NO_2$, $SO_2$ and $PM_{2.5}$) annually with an associated value of A$4,840 /year.

**Table 3 Waite Arboretum Survey - Summary of pollutant removal with A$ value.**

| Pollutant | Kg / year | A$/ tonne | A$ value / year |
|---|---|---|---|
| CO | 2.2 | 23 | $0.05 |
| $NO_2$ | 502 | 612 | $307 |
| $O_3$ | 679 | 4,105 | $2,789 |
| $SO_2$ | 6.8 | 223 | $1.52 |
| $PM_{2.5}$ | 12.2 | 142,612 | $1,742 |
| TOTAL | 1,202 kgs | | $4,840 |

The highest total air pollution removal was by a specimen of Sugar Gum *Eucalyptus cladocalyx* Arboretum ID # 1201G which removed 7.2 kg/yr (value of $26.50/yr). In addition to the 14 other specimens of Sugar Gum in the Arboretum, other specimens which removed four or more kilograms a year included Bunya Pine *Araucaria bidwillii* (1), Canary Island Pine *Pinus canariensis* (3), Lemon-scented Gum *Corymbia citriodora* (1) and Grey Box *Eucalyptus microcarpa* (2).

**Figure 9** **Waite Arboretum Survey - Annual pollution removal (points) and value (bars) from i-Tree Eco Analysis June 2017.**

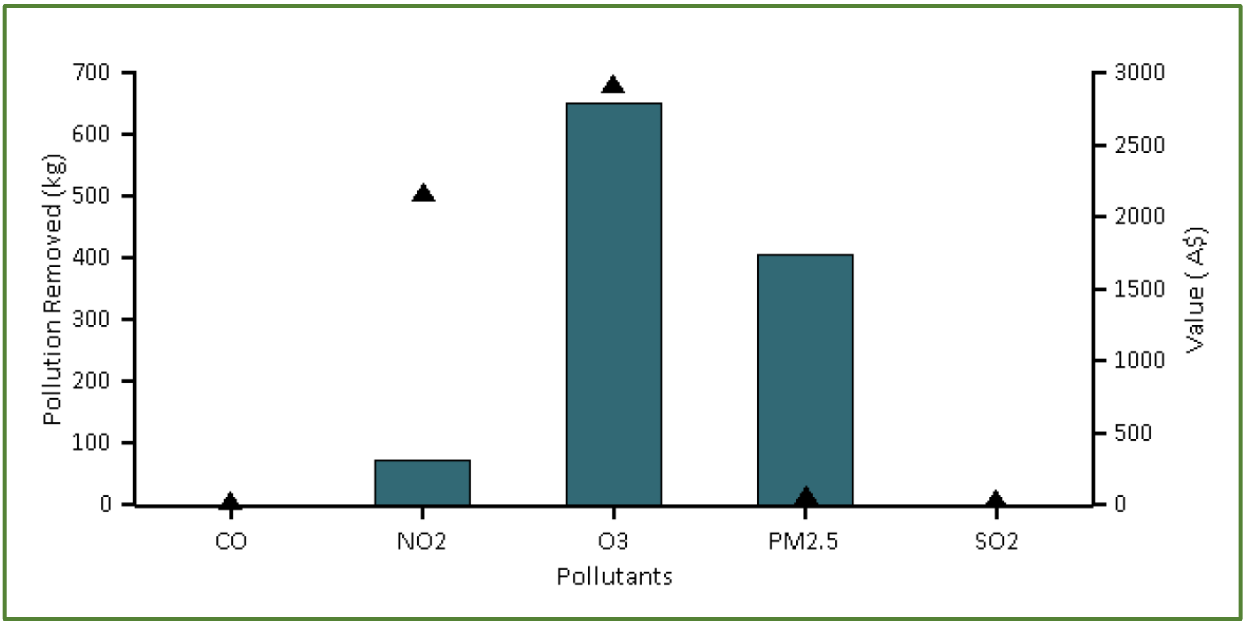



Table 4 lists the top 40 specimens with the greatest $PM_{2.5}$ removal and shows the close correlation with Leaf Area.

Sugar Gum – *Eucalyptus cladocalyx* #1201J
Photo: J. Gardner

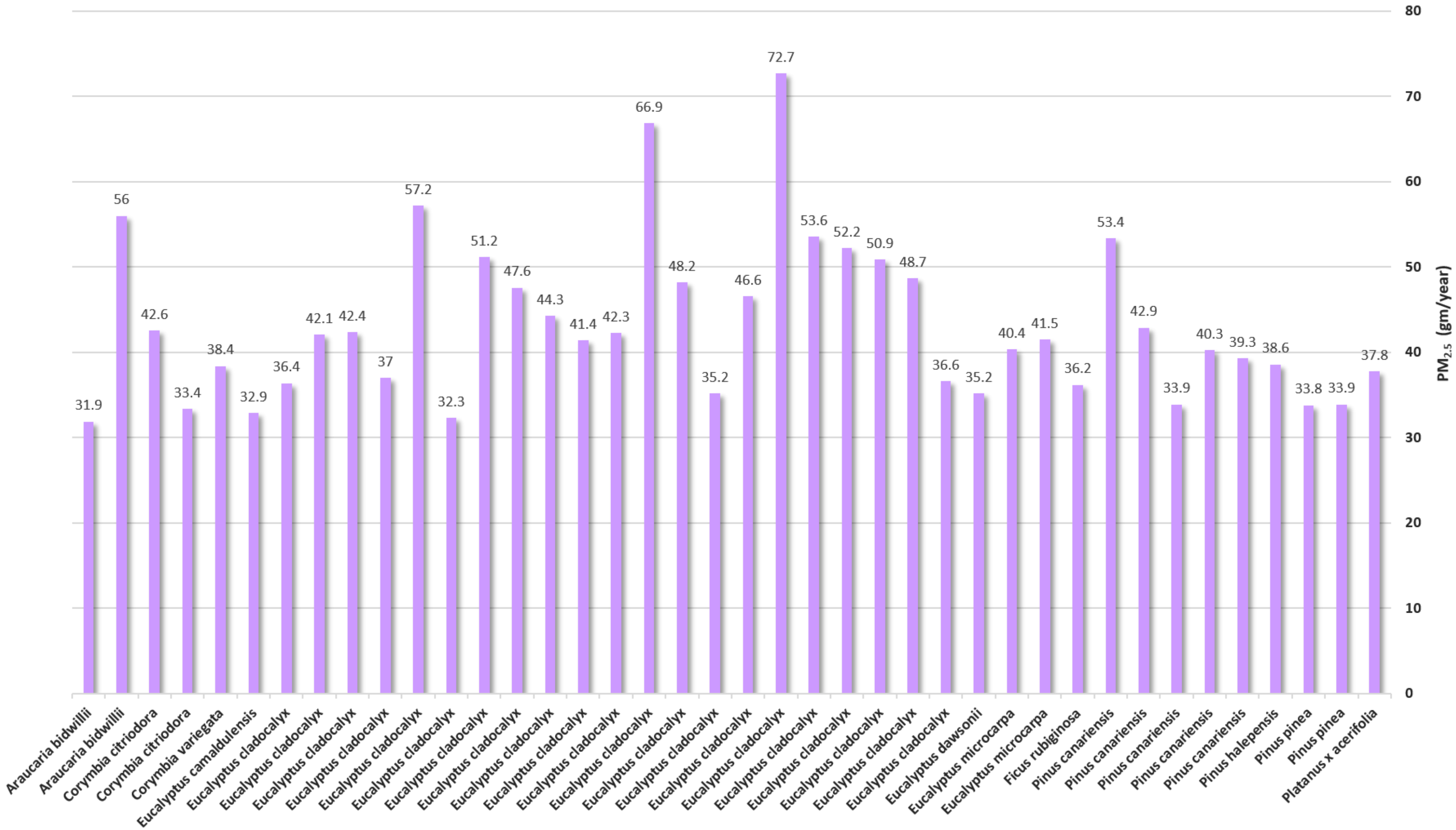
| | |
|---|---|
| Height: | 34 m |
| DBH: | 202 cm |
| Canopy area: | 718 $m^2$ |
| Age: | 140 years |
| Carbon Stored: | 6.2 tonne |
| Total Pollution removed: | 5.3 kg/yr |
| Structural Value: | A$56,891.00 |

**Table 4 Waite Arboretum Survey - Top 40 specimens with the greatest $PM_{2.5}$ removal and the corresponding leaf area.**

| Tree ID | Scientific Name | Common Name | PM2.5 removal (g/yr) | Leaf Area ($m^2$) |
|---|---|---|---|---|
| 1201G | *Eucalyptus cladocalyx* | Sugar Gum | 72.7 | 4,586 |
| 1201D | *Eucalyptus cladocalyx* | Sugar Gum | 66.9 | 4,222 |
| 2153 | *Eucalyptus cladocalyx* | Sugar Gum | 57.2 | 3,606 |
| 1880 | *Araucaria bidwillii* | Bunya Pine | 56.0 | 3,530 |
| 1201J | *Eucalyptus cladocalyx* | Sugar Gum | 53.6 | 3,383 |
| 2144A | *Pinus canariensis* | Canary Island Pine | 53.4 | 3,371 |
| 1201K | *Eucalyptus cladocalyx* | Sugar Gum | 52.2 | 3,290 |
| 41 | *Eucalyptus cladocalyx* | Sugar Gum | 51.2 | 3,229 |
| 1201L | *Eucalyptus cladocalyx* | Sugar Gum | 50.9 | 3,211 |
| 1201M | *Eucalyptus cladocalyx* | Sugar Gum | 48.7 | 3,072 |
| 1201E | *Eucalyptus cladocalyx* | Sugar Gum | 48.2 | 3,039 |
| 2100 | *Eucalyptus cladocalyx* | Sugar Gum | 47.6 | 3,004 |
| 1201F | *Eucalyptus cladocalyx* | Sugar Gum | 46.6 | 2,938 |
| 1201A | *Eucalyptus cladocalyx* | Sugar Gum | 44.3 | 2,797 |
| 1A | *Pinus canariensis* | Canary Island Pine | 42.9 | 2,709 |
| 37 | *Corymbia citriodora* | Lemon-scented Gum | 42.6 | 2,687 |
| 2150D | *Eucalyptus cladocalyx* | Sugar Gum | 42.4 | 2,672 |
| 1201C | *Eucalyptus cladocalyx* | Sugar Gum | 42.3 | 2,666 |
| 2149 | *Eucalyptus cladocalyx* | Sugar Gum | 42.1 | 2,654 |
| 21 | *Eucalyptus microcarpa* | Grey Box | 41.5 | 2,619 |
| 1201B | *Eucalyptus cladocalyx* | Sugar Gum | 41.4 | 2,609 |
| 1522 | *Eucalyptus microcarpa* | Grey Box | 40.4 | 2,546 |
| 2118 | *Pinus canariensis* | Canary Island Pine | 40.3 | 2,544 |
| 2114 | *Pinus canariensis* | Canary Island Pine | 39.3 | 2,478 |
| 2110 | *Pinus halepensis* | Aleppo Pine, Jerusalem Pine | 38.6 | 2,433 |
| 1562 | *Corymbia variegata* | | 38.4 | 2,426 |
| 2144D | *Platanus x acerifolia** | London Plane | 37.8 | 2,386 |
| 2152 | *Eucalyptus cladocalyx* | Sugar Gum | 37.0 | 2,333 |
| 2150L | *Eucalyptus cladocalyx* | Sugar Gum | 36.6 | 2,311 |
| 2143E | *Eucalyptus cladocalyx* | Sugar Gum | 36.4 | 2,299 |
| 948 | *Ficus rubiginosa* | Port Jackson Fig, Rusty Fig | 36.2 | 2,284 |
| 101 | *Eucalyptus cladocalyx* | Sugar Gum | 35.2 | 2,220 |
| 1637 | *Eucalyptus dawsonii* | Slaty Gum | 35.2 | 2,219 |
| 2124 | *Pinus pinea* | Stone Pine | 33.9 | 2,142 |
| 2106 | *Pinus canariensis* | Canary Island Pine | 33.9 | 2,141 |
| 2140 | *Pinus pinea* | Stone Pine | 33.8 | 2,135 |
| 3248 | *Corymbia citriodora* | Lemon-scented Gum | 33.4 | 2,109 |
| 2144B | *Eucalyptus camaldulensis* | River Red Gum | 32.9 | 2,078 |
| 2153A | *Eucalyptus cladocalyx* | Sugar Gum | 32.3 | 2,039 |
| 535 | *Araucaria bidwillii* | Bunya Pine | 31.9 | 2,010 |

*Deciduous

**Figure 10 Waite Arboretum Survey - Top 40 species for fine particulate matter ($PM_{2.5}$) removal.**



The monthly pollution removal in kilograms and corresponding value (A$) of each pollutant analysed are shown in Figures 10 – 16. Figures 11 – 16 were sourced directly from the 'i-Tree Eco Analysis – Benefits Summary' (accessed 3 August 2017)

**Figure 11 Pollution removal in Waite Arboretum Survey in kilograms / month.**

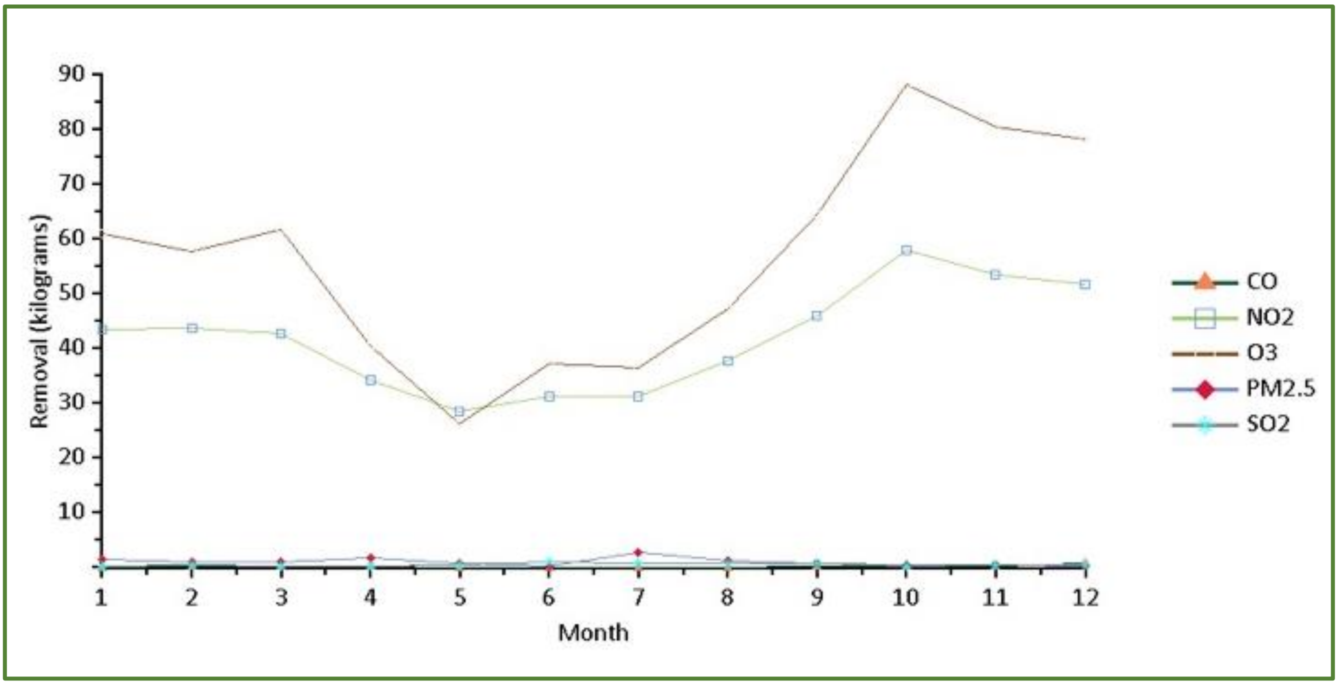



**Figure 12 Pollution Removal in Waite Arboretum Survey in A$ value / month.**

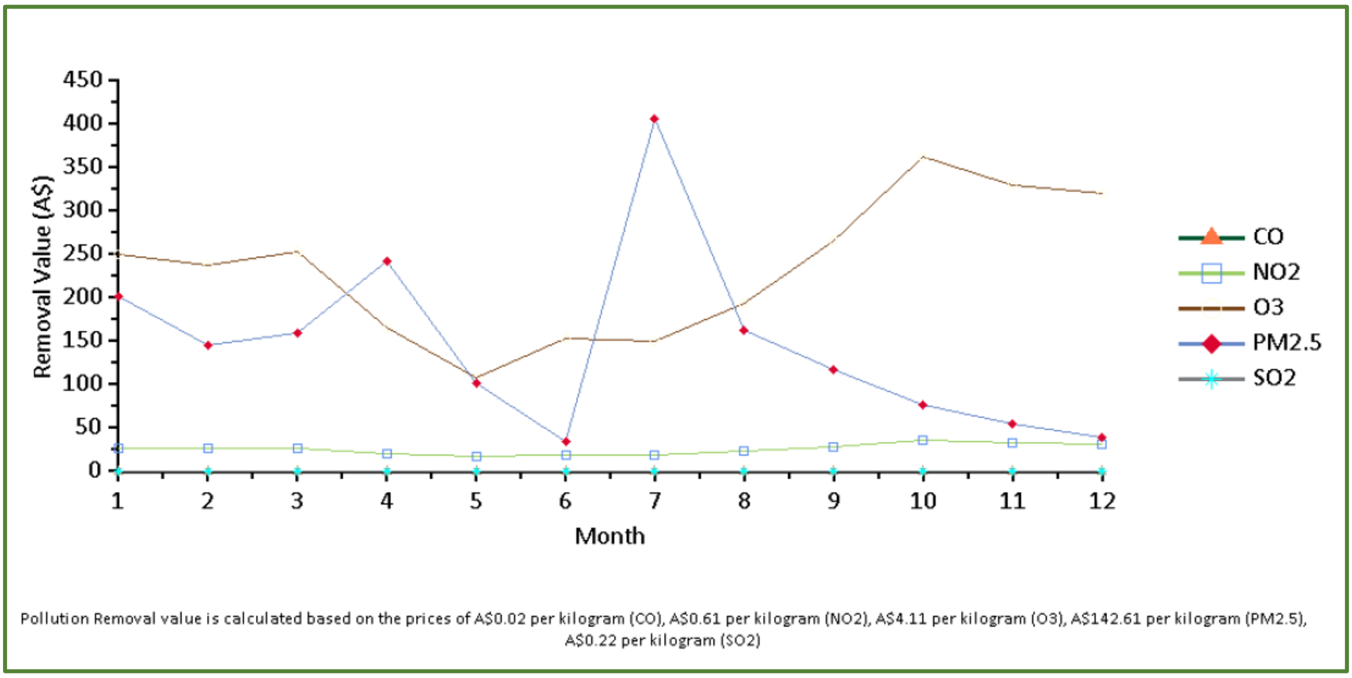


**Figure 13 Pollution removal (CO) in Waite Arboretum Survey by month.**

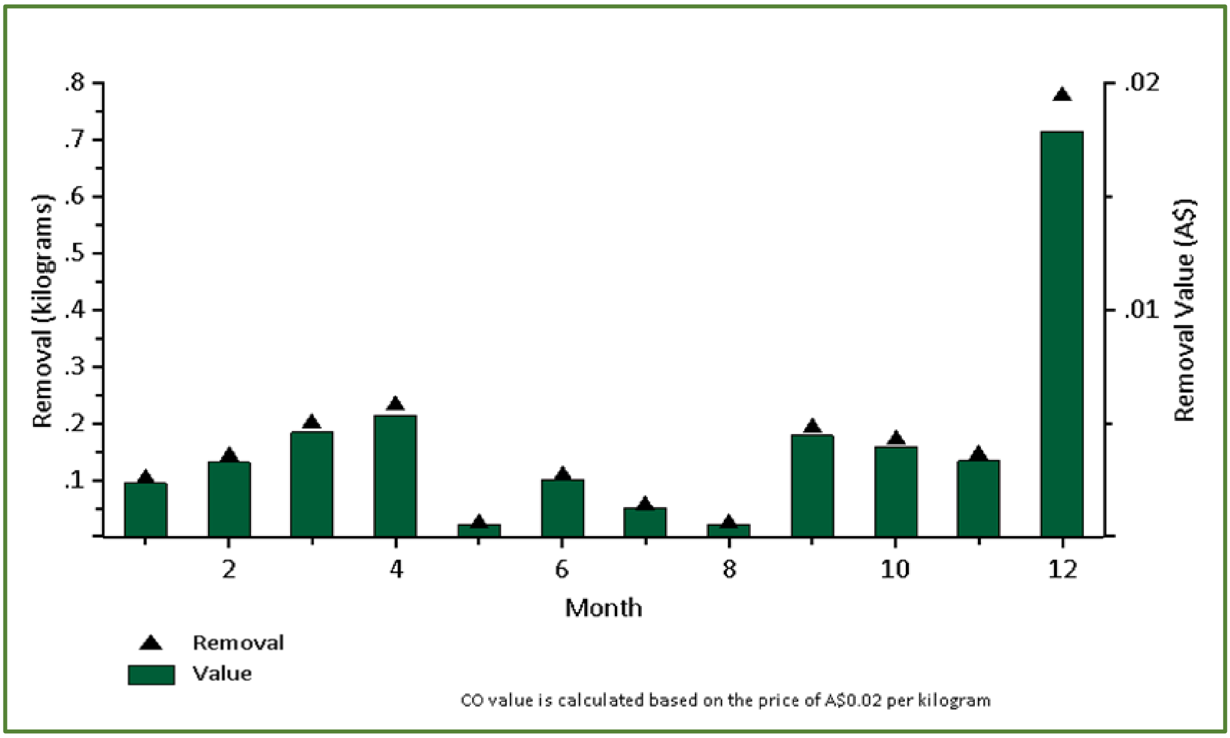



**Figure 14 Pollution removal ($NO_2$) in Waite Arboretum Survey by month.**

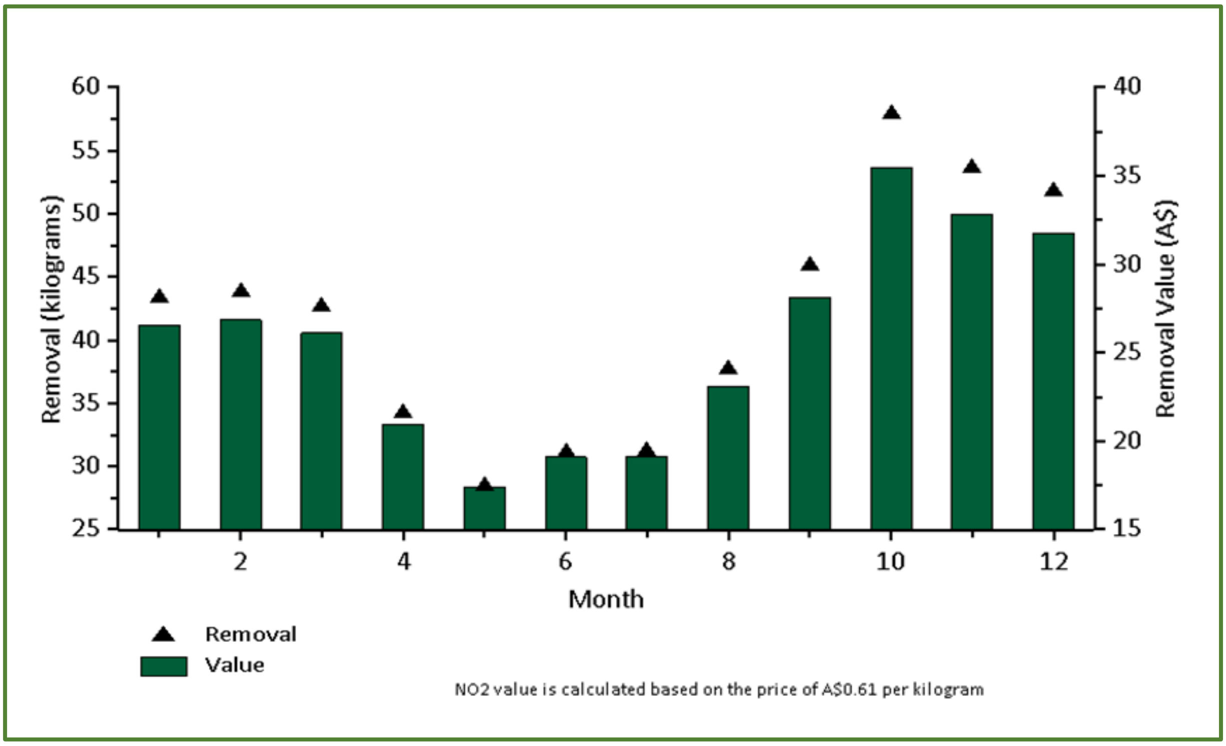


**Figure 15 Pollution removal ($O_3$) in Waite Arboretum Survey by month.**

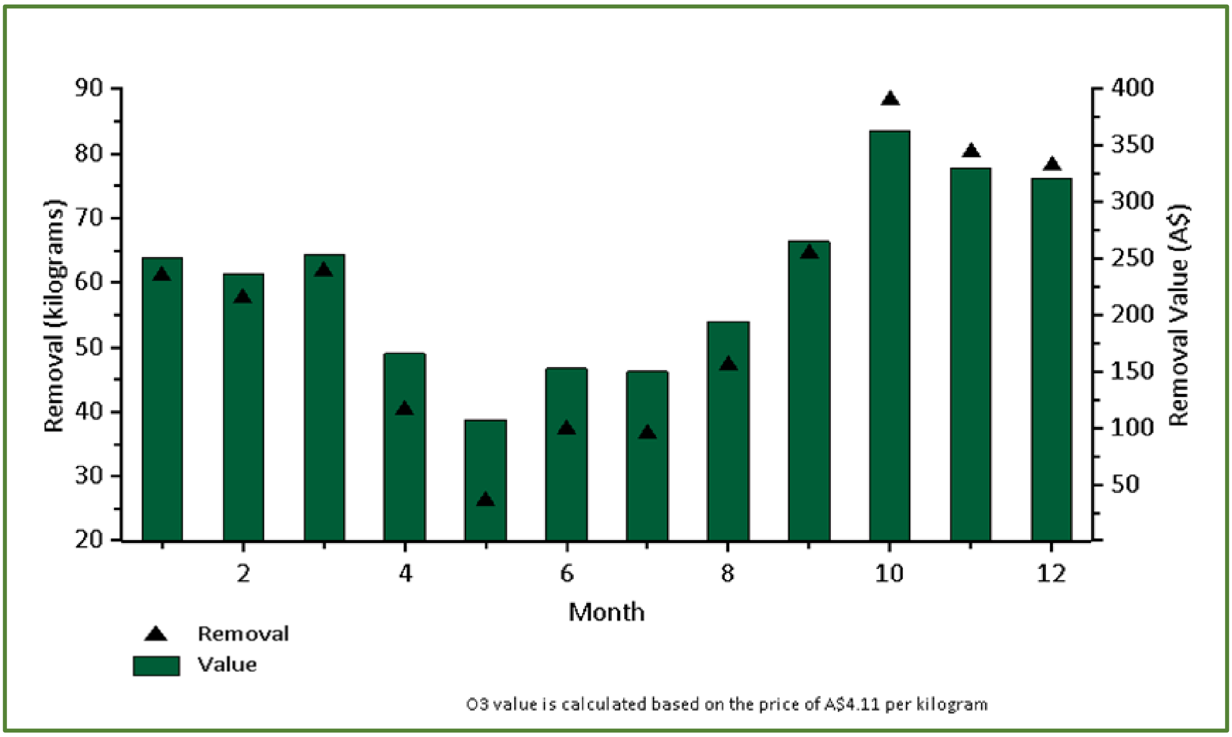



**Figure 16 Pollution removal ($PM_{2.5}$) in Waite Arboretum Survey by month.**

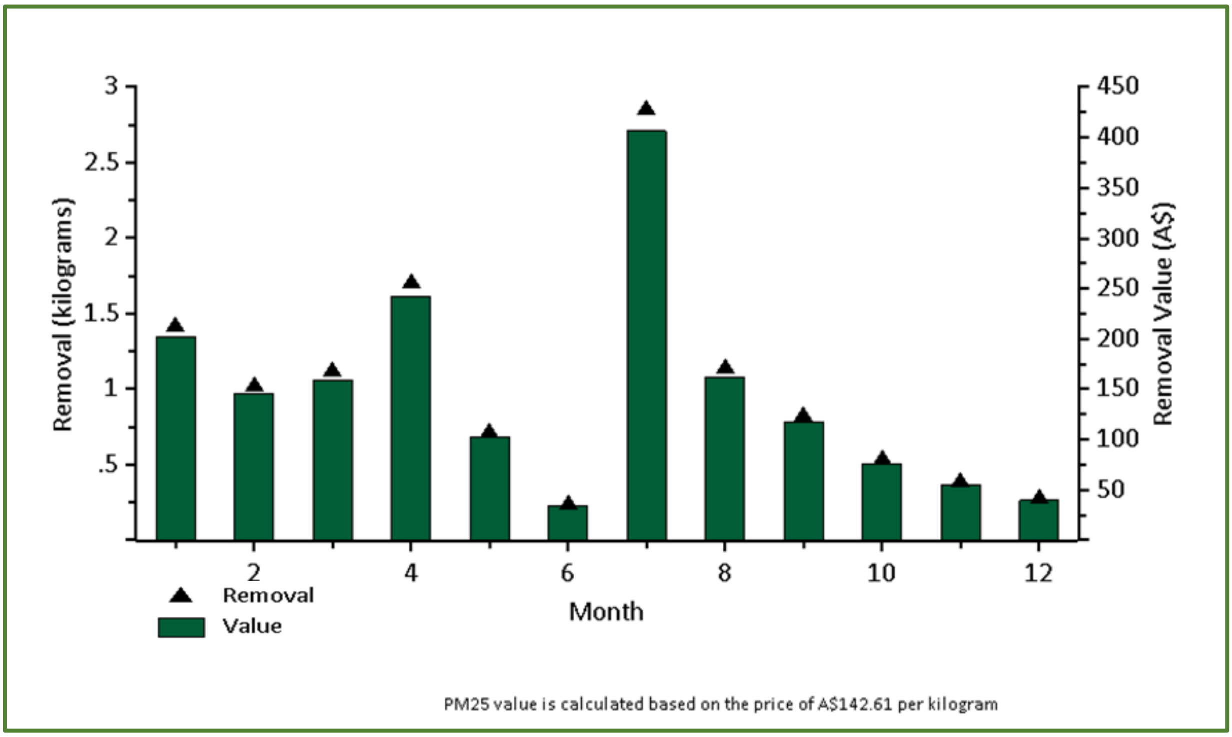
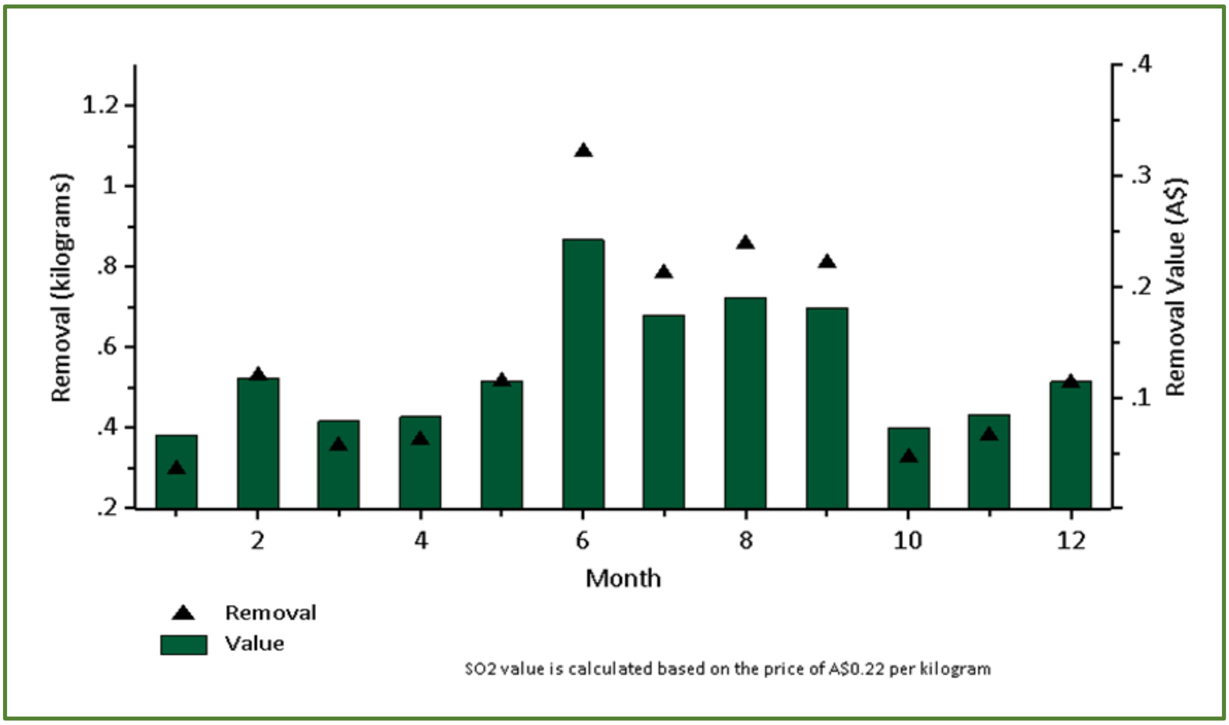


**Figure 17 Pollution removal ($SO_2$) in Waite Arboretum Survey by month.**




## 3.2.2 Carbon sequestration and storage

Carbon sequestration is the removal of $CO_2$ gas from the air by plants, and its storage as carbohydrates. Forests have a vital role in mitigating climate change by sequestering atmospheric $CO_2$, a greenhouse gas. As trees add new growth they increasingly sequester carbon. To derive an estimate of the gross amount of carbon sequestered annually, i-Tree Eco uses:

- Species - to identify biomass equations
- Diameter at Breast Height (DBH) and Total Height - to calculate tree biomass and
- Condition (% dieback) and Crown Light Exposure (CLE) - to adjust growth rates.

The total annual carbon sequestration of the surveyed Arboretum trees was estimated to be 34.3 tonnes/year. The three species which sequestered most carbon were English Elm *Ulmus procera*, Sugar Gum *Eucalyptus cladocalyx* and Lemon-scented Gum *Corymbia citriodora* due to the large numbers of specimens in the Arboretum and their size. The 71 English Elms sequestered approximately 10.2% of all sequestered carbon. The 40 species estimated to sequester the most carbon annually and their respective amount of carbon stored are shown in Figure 18 and listed in Table 5 with A$ value. The total amount of carbon sequestered by the surveyed trees is 34.5 tonnes/year which has a value of A$783/year.

Carbon storage is the amount of carbon sequestered from atmospheric $CO_2$ and stored as carbohydrates in the roots, trunk, branches and leaves of the plants. The i-Tree Eco software calculated the biomass of each tree using equations from the literature and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by the forest equation (Nowak 1994) so open-grown urban trees are multiplied by 0.8. Tree dry-weight biomass is converted to stored carbon by multiplying by 0.5.

Sugar Gums *Eucalyptus cladocalyx* represented 23 of the 25 specimens storing the most carbon, with Port Jackson Fig *Ficus rubiginosa* (Arboretum tree #948) and Grey Box *Eucalyptus microcarp*a (#2125A) the other major contributors. The total carbon stored in the Arboretum surveyed trees was calculated to be 1,167 tonnes which is equivalent to the annual carbon emissions from 910 vehicles or from 373 single family houses. Sugar Gums accounted for approximately 23.3% of the total.

Port Jackson Fig – *Ficus rubiginosa* J. Gardner

As trees mature their vigour declines, growth rate slows and the canopy tends to thin. This has led to the long-held assumptions that the amount and rate of carbon sequestration offered by older trees will decline (Seed Consulting 2016). Stephenson and colleagues (2014) analysed data on 673,046 trees from 403 species in monitored forest plots in both tropical and temperate areas around the world, including 22 species in Australasia, and found that large, old trees do not act simply as senescent carbon reservoirs, but gained the most mass each year in 97% of the species. The study published in *Nature* calculated a 52-fold greater average mass growth rate of trees 100 cm in diameter compared to those 10 cm in diameter. Thus although growth efficiency per unit of leaf area often declines with increasing tree size and age, increases in the tree's total leaf area outpace this decline and cause whole-tree carbon accumulation rate to increase.

In the Waite Arboretum tree survey, however, none of the 55 trees storing the most carbon had a sequestration rate of > 100 kg/year. The range was 10 – 95 kg with an average of 48 kg/year, much less than the ten specimens with the greatest sequestration (Table 5). This may be explained by the fact that many of the mature Sugar Gums, especially those planted in 1877, went into sharp decline in years of below average rainfall (2006 -2015) and lost substantial branches and canopy.

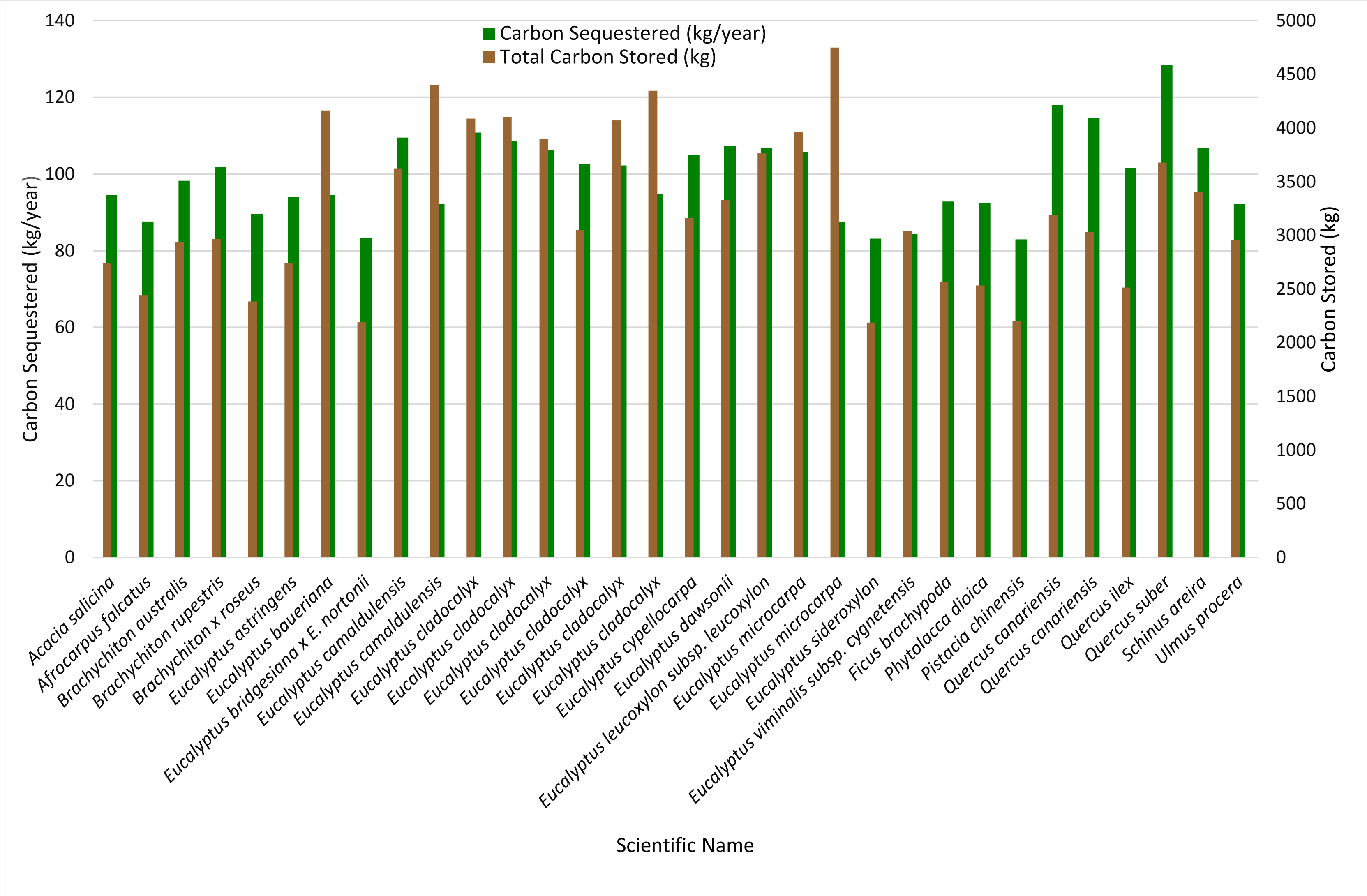
As trees decline in health, die and decay, much of the stored carbon is released back into the atmosphere. Maintaining healthy trees will keep the carbon stored and maximize their environmental benefits. However, tree maintenance (e.g. use of machinery and fuel) can contribute to carbon emissions (Nowak *et al*. 2002c). When a tree dies, using the wood in long-term wood products, to heat buildings or to produce energy will help to reduce carbon emissions from wood decomposition or from fossil-fuel power plants.

Carbon storage and sequestration values are based on estimated or customized local carbon values. For this analysis, carbon storage and carbon sequestration of the Waite Arboretum Survey have been calculated based on A$22.8 per tonne.

**Table 5 Waite Arboretum Survey – Top 40 specimens with the highest rate of carbon sequestration, the corresponding amount of carbon stored and A$ value.**

| Arb. Tree ID | Scientific Name | Common Name | C seq. kg / yr | C stored kg | C store A$ |
|---|---|---|---|---|---|
| 431A | *Quercus suber* | Cork Oak | 129 | 3,677 | 83 |
| 437 | *Quercus canariensis* | Algerian Oak | 118 | 3,189 | 72 |
| 886 | *Quercus canariensis* | Algerian Oak | 115 | 3,029 | 69 |
| 2153 | *Eucalyptus cladocalyx* | Sugar Gum | 111 | 4,087 | 93 |
| 431A | *Eucalyptus camaldulensis* | River Red Gum | 110 | 3,623 | 82 |
| 2156 | *Eucalyptus cladocalyx* | Sugar Gum | 109 | 4,103 | 93 |
| 1637 | *Eucalyptus dawsonii* | Slaty Gum | 107 | 3,327 | 75 |
| 1862 | *Eucalyptus leucoxylon* | Blue Gum | 107 | 3,764 | 85 |
| 2196A | *Schinus areira* | Pepper Tree | 107 | 3,405 | 77 |
| 2154A | *Eucalyptus cladocalyx* | Sugar Gum | 106 | 3,901 | 88 |
| 21 | *Eucalyptus microcarpa* | Grey Box | 106 | 3,960 | 90 |
| 2728 | *Eucalyptus cypellocarpa* | Mountain Grey Gum | 105 | 3,164 | 72 |
| 2157 | *Eucalyptus cladocalyx* | Sugar Gum | 103 | 3,047 | 69 |
| 2150A | *Eucalyptus cladocalyx* | Sugar Gum | 102 | 4,070 | 92 |
| 242B | *Brachychiton rupestris* | Bottle Tree | 102 | 2,965 | 67 |
| 887 | *Quercus ilex* | Holly or Holm Oak | 102 | 2,514 | 57 |
| 248 | *Brachychiton australis* | Broad-leaved Bottle Tree | 98 | 2,938 | 66 |
| 2145D | *Eucalyptus cladocalyx* | Sugar Gum | 95 | 4,346 | 99 |
| 1507A | *Eucalyptus baueriana* | Blue Box | 95 | 4,162 | 94 |
| 2173 | *Acacia salicina* | Broughton Willow | 95 | 2,740 | 62 |
| 57 | *Eucalyptus astringens* | Brown Mallet | 94 | 2,740 | 62 |
| 199 | *Ficus brachypoda* | Small-leaved Rock Fig | 93 | 2,569 | 58 |
| 971 | *Phytolacca dioica* | Bella Sombra, Pokeberry | 92 | 2,532 | 57 |
| 2145B | *Eucalyptus camaldulensis* | River Red Gum | 92 | 4,398 | 100 |
| 1143 | *Ulmus procera* | English Elm | 92 | 2,956 | 67 |
| 6 | *Brachychiton x roseus* | Wentworth Flame Tree | 90 | 2,384 | 54 |
| 540 | *Afrocarpus falcatus* | Outeniqua, Yellowwood | 88 | 2,441 | 55 |
| 1522 | *Eucalyptus microcarpa* | Grey Box | 87 | 4,749 | 108 |
| 88B | *Eucalyptus viminalis subsp. cygnetensis* | Rough-barked Manna Gum | 84 | 3,041 | 69 |
| 1602 | *Eucalyptus bridgesiana x E. nortonii* | | 83 | 2,191 | 49 |
| 1617 | *Eucalyptus sideroxylon* | Mugga, Red Ironbark | 83 | 2,187 | 49 |
| 862 | *Pistacia chinensis* | Chinese Pistachio | 83 | 2,199 | 50 |
| 1562 | *Corymbia variegata* | | 82 | 2,227 | 50 |
| 34 | *Corymbia variegata* | | 82 | 2,172 | 49 |
| 2184 | *Acacia salicina* | Broughton Willow | 81 | 2,102 | 47 |
| 1911B | *Eucalyptus spathulata* | Swamp Mallet | 81 | 2,150 | 49 |
| 2144D | *Platanus x acerifolia* | London Plane | 80 | 1,934 | 44 |
| 1120 | *Ulmus procera* | English Elm | 80 | 2,287 | 52 |
| 242A | *Brachychiton rupestris* | Bottle Tree | 79 | 1,946 | 44 |
| 2749 | *Eucalyptus cypellocarpa* | Mountain Grey Gum | 78 | 1,915 | 44 |

**Figure 18 Specimens with the highest rate of carbon sequestration and the corresponding carbon stored.**



### 3.2.3 Oxygen production

Oxygen production is one of the most commonly cited benefits of trees. The annual oxygen production of a tree through photosynthesis is directly related to the amount of carbon sequestered by the tree and the accumulation of tree biomass. Further details are given in Appendix 1. The top 20 oxygen producing species are listed in Table 6.

**Table 6 Top oxygen producing species / genera**
Source:" i-Tree Ecosystem Analysis Waite Arboretum Inventory June 2017"

| *Species* | *Oxygen (tonne)* | *Gross Carbon Sequestration (kilogram/yr)* | *Number of Trees* | *Leaf Area (hectare)* |
|---|---|---|---|---|
| Ulmus procera | 9.37 | 3,512.43 | 71 | 9.19 |
| Eucalyptus cladocalyx | 6.56 | 2,460.28 | 60 | 10.42 |
| Corymbia citriodora | 5.51 | 2,066.12 | 54 | 7.18 |
| Eucalyptus camaldulensis | 2.25 | 842.99 | 17 | 1.54 |
| Eucalyptus | 2.11 | 792.22 | 34 | 1.34 |
| Pinus canariensis | 1.86 | 698.49 | 22 | 3.08 |
| Brachychiton acerifolius | 1.62 | 608.81 | 14 | 0.68 |
| Quercus canariensis | 1.48 | 555.98 | 9 | 0.80 |
| Eucalyptus microcarpa | 1.36 | 511.69 | 11 | 1.10 |
| Pyrus | 1.24 | 466.52 | 37 | 0.49 |
| Quercus | 1.21 | 453.77 | 13 | 0.43 |
| Pinus halepensis | 1.16 | 434.36 | 15 | 1.56 |
| Pinus pinea | 1.15 | 431.03 | 13 | 1.74 |
| Araucaria bidwillii | 0.78 | 291.26 | 7 | 1.36 |
| Magnoliopsida | 0.76 | 286.69 | 11 | 0.25 |
| Corymbia | 0.76 | 284.89 | 6 | 0.42 |
| Syzygium paniculatum | 0.71 | 264.63 | 6 | 0.37 |
| Araucaria cunninghamii | 0.68 | 254.26 | 5 | 0.31 |
| Flindersia australis | 0.66 | 248.27 | 4 | 0.36 |
| Eucalyptus astringens | 0.61 | 230.46 | 6 | 0.36 |

Surveyed trees in Waite Arboretum are estimated to produce 91.5 tonnes of oxygen a year. However, this tree benefit is relatively insignificant because of the large, relatively stable amount of oxygen in the atmosphere and the production of oxygen by aquatic systems. If all fossil fuel reserves, all trees and all organic matter in soils were burned, atmospheric oxygen would only drop a few percent (Broecker 1970).

### 3.2.4 Volatile Organic Compounds (VOCs) emissions

Trees emit the volatile organic compounds (VOCs), isoprenes and monoterpenes, which are precursor chemicals to ozone formation. However, in atmospheres with low nitrogen oxide concentrations (e.g. some rural environments), VOCs may remove ozone (Nowak 2002). Total VOC emissions are temperature dependent. An increase in tree cover leads to reduced air temperatures which in turn significantly reduces daytime ozone concentrations (Nowak *et al*. 2000). Integrative studies have shown that trees, particularly low VOC emitting species, can be a viable strategy to help reduce urban ozone levels (Nowak *et al*. 2014). Stress on trees can increase overall VOC emissions[26] which is another reason to maintain healthy trees.

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[26] https://instaar.colorado.edu/outreach/trees-and-vocs/index.html

Recent research by the CLOUD experiment, a collaboration between around 80 scientists at the CERN particle physics lab near Geneva, has changed our understanding of the role trees play in cloud formation. Most cloud droplets require tiny airborne particles to act as 'seeds'. The more seeds, the more droplets form and the more sunlight is reflected away from the Earth. Gaseous terpene emissions from trees clump together, helping with new airborne particle formation and hence cloud formation, contributing to the cooling of the planet (Gordon and Scott, 2016).

In total, the Waite Arboretum surveyed trees emitted an estimated 2.57 tonnes of VOCs: 2.01 tonnes of isoprene and 0.56 tonnes of monoterpenes. The i-Tree Eco Analysis lists the total VOC emissions in g/year for each specimen. Emissions vary between specimens based on species characteristics and amount of leaf biomass. VOC emissions are correlated with canopy area, therefore a rate of g/year/$m^2$ canopy area was calculated as a more meaningful indicator of efficacy of different species.

Genera in the Waite Arboretum survey with high monoterpene formation include *Acacia*, *Cedrus*, *Corymbia*, *Eucalyptus* and *Pinus*. Genera with high isoprene formation include *Casuarina*, *Corymbia*, *Eucalyptus*, *Ficus*, *Pinus, Platanus* and *Quercus*. Some species with a high rate of VOC emissions e.g. *Eucalyptus cladocalyx* (38 g/year/$m^2$ canopy area) also have the highest rates of ozone reduction.

Genera and species with high environmental benefits (pollution removal, shade and avoided runoff) and a suitable size for street and amenity planting with low calculated rates of total VOC emissions (<5g/year/ $m^2$ canopy area) are presented in Table 7.

**Table 7 Waite Arboretum Survey – Genera and species with the lowest rates of total VOC emissions.**

| **Genus** | **Species** |
|---|---|
| AUSTRALIAN NATIVE | |
| *Brachychiton* | *acerifolius, australis, discolour, populneus, x roseus* |
| *Corymbia* | *calophylla, citriodora* |
| *Ficus* | *brachypoda,. macrophylla,. rubiginosa* |
| *Flindersia* | *australis, maculosa, xanthoxlya* |
| *Hymenosporum* | *flavum* |
| *Lophostemon* | *confertus* |
| *Melaleuca* | *styphelioides* |
| *Mischocarpus* | *pyriformis* |
| *Podocarpus* | *elatus* |
| *Syzygium* | *paniculatum* |
| EXOTIC | |
| *Fraxinus* | *americana* |
| *Gleditsia* | *triacanthus* |
| *Jacaranda* | *mimosifolia* |
| *Lagerstroemia* | *indica* |
| *Melia* | *azedarach* |
| *Nuxia* | *floribunda* |
| *Photinia* | *serrulata* |
| *Paulownia* | *tomentosa* |
| *Pyrus* | *species* |
| *Ulmus* | *procera* |

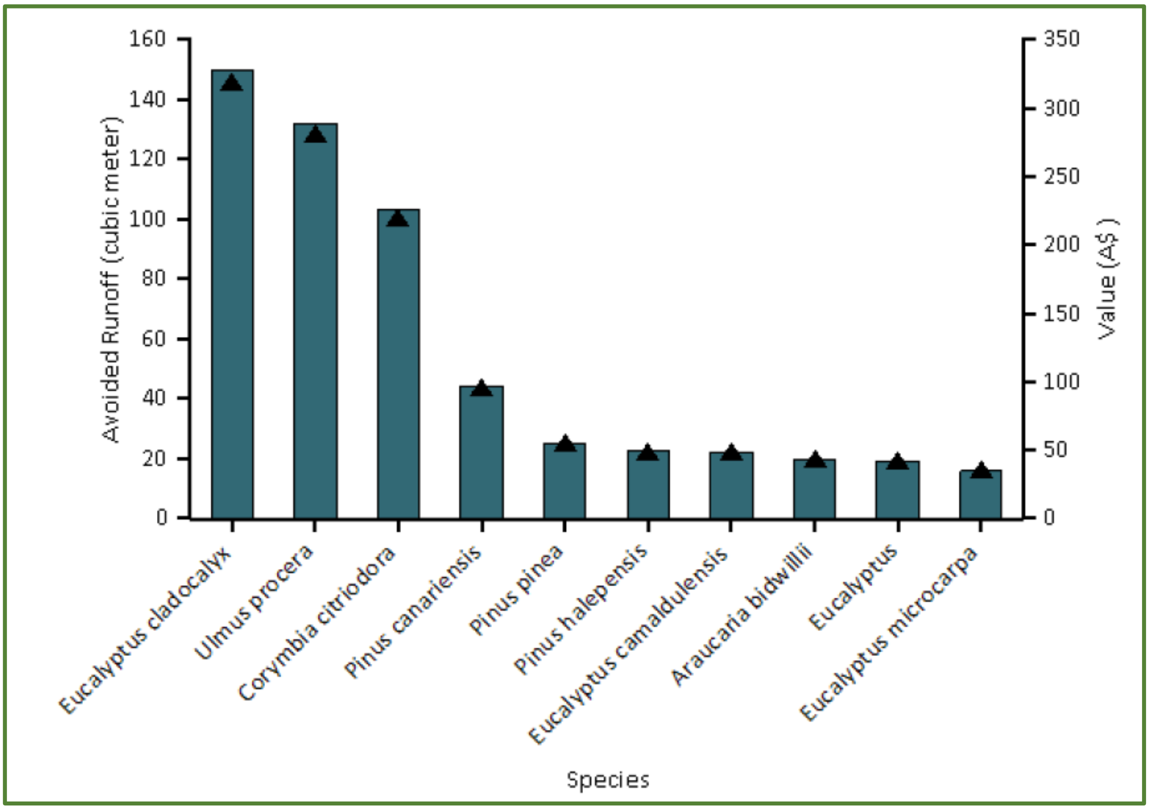
### 3.2.5 Avoided run-off

Trees have been shown to intercept large volumes of rainwater, significantly reducing stormwater runoff. Trees can also increase soil infiltration as the leaves and branches intercept, absorb and temporarily store water before it evaporates, allowing gradual infiltration into the soil (Beecham and Lucke 2015).

In i-Tree Eco analyses annual avoided surface runoff is calculated based on rainfall interception by vegetation, specifically the difference between annual runoff with and without vegetation. Although tree leaves, branches and bark may intercept precipitation and thus mitigate surface runoff, only the precipitation intercepted by leaves is accounted for in this analysis. The value of avoided run-off is based on user defined local values for the Waite Arboretum Survey. Avoided run-off value was calculated based on the price of A$2.262/$m^3$ (Appendix 1).

In the Waite Arboretum survey the avoided surface runoff was calculated for an annual rainfall of 120 mm. However, the Australian Government Bureau of Meteorology station, Adelaide (Waite Institute - Station 023031 which operated 1925 to 1999) adjacent to the Waite Arboretum, recorded an average annual rainfall over the 74 years of 618 mm. The i-Tree Eco model uses weather from the National Climatic Data Center (NCDC). Local climate data derived from six hour precipitation events were converted to one hourly events to be integrated into the model's underlying database. This resulted in the avoided run-off value being underestimated in most cases for Australian cities[27]. Figure 19 shows avoided runoff based on the 120 mm annual rainfall.

**Figure 19 Avoided runoff and value for species with the greatest overall impact on runoff.**
Source: "iTree Ecosystem Analysis Waite Arboretum Survey June 2017"




[27] Email correspondence from Al Zelaya, i-Tree Technical Services dated 24 May 2017

### 3.2.6 Environmental Benefits Overview – Value in dollars and sense

Trees have been consistently undervalued in our modern urban environment. They are often only seen as causes of negative outcomes such as damage to buildings and infrastructure (particularly during storm events or often mistakenly root system invasions), the production of leaf litter (clogging up drains) and fruit fall causing potential slip hazard to pedestrians. In addition, trees are seen as impediments to road safety. However if properly selected, adequately spaced and pruned, they do not create major visibility problems (Sanders *et al.* 2012, Dixon and Wolf, 2007). Roadside trees are also unfairly blamed for damage to vehicles and injuries to people, when in fact the tree collision is simply the outcome of a vehicle running off the road (Heart Foundation 2017).

There is a growing body of scientific research that is showing that trees in our urban environment are vital to the health and wellbeing of people and an essential component for liveable cities (Mitchell and Popham 2008, De Vries *et al*. 2003,). The climate is steadily warming and "wilding", including an apparent increase in the recently named phenomena "rain bombs"[28] (Butler 2016). Considering the changes to climate and the increased frequency of extreme weather events such as heat waves and storms, urban green spaces contribute to the resilience of cities facing these often costly occurrences (Davern *et al*. 2016). The i-Tree Eco analysis provides quantified dollar values for specific services provided by trees in our city and urban environments. These services are calculated under the following criteria:

- Air Pollution Removal (Air quality improvement)
- Carbon Storage and Sequestration (greenhouse gas emission reduction)
- Stormwater management (Avoided runoff).

From the analysis, the top 40 performers (in relation to total value of environmental benefits) were selected (Table 8). The average Diameter at Breast Height (DBH) in this selection is 136 cm. Large healthy trees with diameter greater than 77 cm remove approximately 70 times more air pollution annually than small healthy trees less than 8 cm in diameter (Nowak 2002). The overall rated condition of the health of this selection ranges from 'Good' (52.5%) to 'Excellent' (47.5%).

Research has also shown that older larger trees can provide up to 60 times greater pollution reduction benefit than smaller trees (Heart Foundation 2017). For the Top 40 trees with the highest environmental benefits in Table 8, the average age is 111 years, with a minimum age of 48 and a maximum of 140 years.

Natural hydrological processes are dramatically altered by impervious surfaces such as roads and building. Green spaces and permeable surfaces slow and filter rainfall run off, improving water quality, reducing flooding and waterway pollutants (Davern *et al.* 2016). In relation to stormwater management (avoided runoff) the Top 40 trees reduced rainfall runoff by 1,070 $m^3$ (an average of 27 $m^3$/tree) with a total dollar value of A$2,424. However, the actual amount of avoided runoff is greater than this because, as noted in section 3.2.5, the i-Tree Eco calculation is based on a rainfall of 120 mm which is only 16% of the 74 year average annual rainfall of 618 mm at the Waite Arboretum.

[28] http://metro.co.uk/2015/08/20/watch-rare-rain-bomb-explode-over-arizona-at-150mph-5351672/

When assigning dollar values to the environmental services provided by trees, the extent of the value of trees in our cities and urban environments is sometimes neglected. Trees can do so much more than simply reduce the cost of providing clean air and comfortable living spaces. Noise buffering is a major benefit provided by trees to which it is difficult to assign a dollar value. Large trees attenuate low-frequency noise such as traffic rumble, while vegetation belts of 1.5 - 3m width can significantly reduce perceived and actual noise directly (e.g. absorption) and indirectly (e.g. reduced wind) (Davern *et al.* 2016).

The environmental benefits of each tree surveyed are available on ArcGIS online map 'Waite Arboretum Inventory'- http://arcg.is/1iTTCy

This map shows all of the surveyed trees and the environmental benefits assigned to each as a result of the iTree Eco analysis. This information can be accessed by zooming in and clicking on the polygon to select an individual tree, which will then open a dialogue box displaying these details:

- Arboretum Tree ID
- Height
- DBH
- Tree Age
- Scientific Name
- Common Name
- Canopy Area ($m^2$)
- Structural Value
- Carbon Stored
- Carbon Sequestered
- Total Pollution Removal

| | |
|---|---|
| Height: | 11 m |
| DBH: | 89 cm |
| Canopy area: | 568 $m^2$ |
| Age: | 89 years |
| Carbon Stored: | 2.6 tonne |
| Pollution removed: | 2 kg/yr |
| Structural Value: | A$25,047 |

Small Leaved Rock Fig - *Ficus brachypoda* #199 Photo: J. Gardner

## Table 8 Waite Arboretum Survey – Top 40 specimens with the highest Total Environmental Benefits A$ value.

| Arb Tree ID | Scientific Name | Common Name | C Seq. (kg/yr) | Tot C Stored (kg) | Air PR (g/yr) | Tot EBs (A$/yr) | Leaf Area (m²) | Ht (m) | Can. Area (m²) | SV (A$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1201G | Eucalyptus cladocalyx | Sugar Gum | 10 | 6,237 | 7,155 | $43 | 4,586 | 35 | 891 | 54,671 |
| 1201D | Eucalyptus cladocalyx | Sugar Gum | 14 | 6,190 | 6,588 | $40 | 4,222 | 32 | 1,169 | 54,79 |
| 2153 | Eucalyptus cladocalyx | Sugar Gum | 111 | 4,087 | 5,627 | $36 | 3,606 | 31 | 844 | 31,839 |
| 1880 | Araucaria bidwillii | Bunya Pine | 70 | 3,331 | 5,508 | $35 | 3,530 | 27 | 401 | 46,188 |
| 2144A | Pinus canariensis | Canary Islands Pine | 71 | 3,283 | 5,259 | $33 | 3,371 | 29 | 760 | 46,553 |
| 1201J | Eucalyptus cladocalyx | Sugar Gum | 10 | 6,175 | 5,279 | $32 | 3,383 | 34 | 718 | 56,891 |
| 1201K | Eucalyptus cladocalyx | Sugar Gum | 10 | 6,170 | 5,134 | $31 | 3,290 | 27 | 743 | 58,135 |
| 41 | Eucalyptus cladocalyx | Sugar Gum | 19 | 6,032 | 5,038 | $31 | 3,229 | 28 | 686 | 49,489 |
| 1201L | Eucalyptus cladocalyx | Sugar Gum | 12 | 6,157 | 5,010 | $31 | 3,211 | 28 | 624 | 58,941 |
| 1201M | Eucalyptus cladocalyx | Sugar Gum | 10 | 6,159 | 4,793 | $29 | 3,072 | 33 | 706 | 57,921 |
| 1201E | Eucalyptus cladocalyx | Sugar Gum | 12 | 6,153 | 4,741 | $29 | 3,039 | 30 | 688 | 58,779 |
| 2100 | Eucalyptus cladocalyx | Sugar Gum | 12 | 6,145 | 4,686 | $29 | 3,004 | 37 | 543 | 55,001 |
| 1201F | Eucalyptus cladocalyx | Sugar Gum | 14 | 6,136 | 4,585 | $28 | 2,938 | 30 | 591 | 53,901 |
| 21 | Eucalyptus microcarpa | Grey Box | 106 | 3,960 | 4,086 | $27 | 2,619 | 25 | 647 | 30,884 |
| 1A | Pinus canariensis | Canary Islands Pine | 64 | 2,633 | 4,227 | $27 | 2,709 | 32 | 499 | 40,216 |
| 37 | Corymbia citriodora | Lemon-scented Gum | 66 | 1,469 | 4,192 | $27 | 2,687 | 20 | 769 | 15,338 |
| 1201A | Eucalyptus cladocalyx | Sugar Gum | 14 | 6,065 | 4,365 | $27 | 2,797 | 27 | 633 | 53,820 |
| 2150D | Eucalyptus cladocalyx | Sugar Gum | 57 | 4,487 | 4,168 | $26 | 2,672 | 30 | 658 | 34,439 |
| 2149 | Eucalyptus cladocalyx | Sugar Gum | 45 | 5,240 | 4,140 | $26 | 2,654 | 31 | 679 | 38,941 |
| 1522 | Eucalyptus microcarpa | Grey Box | 87 | 4,749 | 3,973 | $26 | 2,546 | 22 | 629 | 35,592 |
| 1201C | Eucalyptus cladocalyx | Sugar Gum | 14 | 6,113 | 4,159 | $25 | 2,666 | 30 | 676 | 56,451 |
| 1201B | Eucalyptus cladocalyx | Sugar Gum | 10 | 6,135 | 4,070 | $25 | 2,609 | 30 | 533 | 61,197 |
| 1562 | Corymbia variegata | | 82 | 2,227 | 3,785 | $25 | 2,426 | 25 | 569 | 20,662 |
| 2118 | Pinus canariensis | Canary Island Pine | 31 | 884 | 3,969 | $25 | 2,544 | 25 | 496 | 17,466 |
| 2114 | Pinus canariensis | Canary Island Pine | 52 | 2,003 | 3,866 | $25 | 2,478 | 30 | 457 | 33,298 |
| 2144D | Platanus x acerifolia | London plane | 80 | 1,934 | 3,723 | $24 | 2,386 | 18 | 518 | 17,736 |
| 2110 | Pinus halepensis | Aleppo Pine | 45 | 1,599 | 3,796 | $24 | 2,433 | 21 | 673 | 32,599 |
| 1637 | Eucalyptus dawsonii | Slaty Gum | 107 | 3,327 | 3,463 | $23 | 2,219 | 22 | 450 | 28,680 |
| 2150L | Eucalyptus cladocalyx | Sugar Gum | 48 | 5,710 | 3,605 | $23 | 2,311 | 32 | 441 | 43,113 |
| 2152 | Eucalyptus cladocalyx | Sugar Gum | 16 | 5,990 | 3,640 | $22. | 2,333 | 31 | 443 | 48,416 |
| 2144B | Eucalyptus camaldulensis | River Red Gum | 110 | 3,623 | 3,243 | $22 | 2,078 | 19 | 486 | 29,587 |
| 2143E | Eucalyptus cladocalyx | Sugar Gum | 13 | 6,015 | 3,587 | $22 | 2,299 | 28 | 473 | 50,360 |
| 948 | Ficus rubiginosa | Port Jackson Fig | 13 | 5,965 | 3,563 | $22 | 2,284 | 18 | 566 | 60,966 |
| 101 | Eucalyptus cladocalyx | Sugar Gum | 37 | 5,291 | 3,464 | $22 | 2,220 | 25 | 718 | 39,135 |
| 3248 | Corymbia citriodora | Lemon-scented Gum | 75 | 1,875 | 3,291 | $22 | 2,109 | 29 | 425 | 18,023 |
| 2140 | Pinus pinea | Stone Pine | 50 | 2,153 | 3,331 | $21 | 2,135 | 20 | 610 | 37,149 |
| 2124 | Pinus pinea | Stone Pine | 44 | 1,545 | 3,341 | $21 | 2,142 | 21 | 458 | 32,229 |
| 2106 | Pinus canariensis | Canary Island Pine | 42 | 1,308 | 3,340 | $21 | 2,141 | 28 | 394 | 25,215 |
| 1617 | Eucalyptus sideroxylon | Mugga, Red Ironbark | 83 | 2,187 | 3,096 | $21 | 1,985 | 23 | 402 | 20,796 |
| 2153A | Eucalyptus cladocalyx | Sugar Gum | 59 | 4,233 | 3,182 | $21 | 2,039 | 28 | 564 | 33,281 |

Green spaces in cities increase biodiversity and a diversity of understorey and canopy vegetation with leaf litter, long grass, logs, streams and ponds provide habitat structure which is of critical importance to animal diversity. The Waite Arboretum has all of these assets and this is reflected in the wildlife inventory listed in Section 4.3.

Northwest Waite Arboretum eucalypts with native understorey Photo: J. Gardner

Located only five kilometres from the Central Business District of Adelaide, the 27 hectares of the Waite Arboretum provide substantial public green space in an otherwise highly urban environment. Trees in Waite Arboretum provide multiple benefits to the surrounding area, its occupants and visitors.

Northeast Waite Arboretum looking east to the Adelaide Hills Photo: J. Gardner

## 3.3 Structural Value

Structural Value is the value of a tree based on the physical resource itself (e.g. the cost of having to replace a tree with a similar tree). Structural Values were based on valuation procedures of the Council of Tree and Landscape Appraisers, which uses tree species, diameter, condition and local information (Nowak *et al*. 2002a, 2002b). Table 9 lists the 40 specimens in the survey which have the greatest Structural Value.

In summary the top 40 specimens have an:

- Average Structural Value: $40,968
- Average Height: 27 metres
- Average Leaf Area: 2,725 square metres
- Average Canopy Area: 606 square metres

The structural value of each tree in the Waite Arboretum survey (50% of the collection) is given in ArcGIS Online map http://arcg.is/1iTTCy. The total of the Structural Value is estimated to be A$13 million.

Stone Pine – *Pinus pinea* #304 native to the Iberian Peninsula of Southern Europe Photo: J. Gardner

Height: 16 m DBH: 133 cm Canopy Area: 710 $m^2$ Age: 49 years
Structural Value: A$43,727 Carbon Stored: 2.4 tonnes Carbon Sequestered: 55 kg/year
Total Pollution Removed: 2.6 kg/year

**Table 9 Waite Arboretum Survey - specimens with the highest Structural Value and corresponding height and DBH.**

| Arb. Tree ID | Scientific Name | Common Name | Structural Value (A$) | Height (m) | DBH (cm) |
|---|---|---|---|---|---|
| 1201B | *Eucalyptus cladocalyx* | Sugar Gum | $61,196 | 30 | 211 |
| 948 | *Ficus rubiginosa* | Port Jackson Fig, Rusty Fig | $60,965 | 18 | 198 |
| 1201L | *Eucalyptus cladocalyx* | Sugar Gum | $58,941 | 28 | 196 |
| 1201E | *Eucalyptus cladocalyx* | Sugar Gum | $58,779 | 30 | 196 |
| 1201K | *Eucalyptus cladocalyx* | Sugar Gum | $58,135 | 27 | 211 |
| 1201M | *Eucalyptus cladocalyx* | Sugar Gum | $57,920 | 33 | 210 |
| 1201J | *Eucalyptus cladocalyx* | Sugar Gum | $56,890 | 34 | 203 |
| 1201C | *Eucalyptus cladocalyx* | Sugar Gum | $56,450 | 30 | 184 |
| 2140E | *Eucalyptus cladocalyx* | Sugar Gum | $55,325 | 29 | 178 |
| 2100 | *Eucalyptus cladocalyx* | Sugar Gum | $55,001 | 37 | 170 |
| 1201D | *Eucalyptus cladocalyx* | Sugar Gum | $54,798 | 32 | 176 |
| 1201G | *Eucalyptus cladocalyx* | Sugar Gum | $54,670 | 35 | 190 |
| 1201F | *Eucalyptus cladocalyx* | Sugar Gum | $53,900 | 30 | 186 |
| 1201A | *Eucalyptus cladocalyx* | Sugar Gum | $53,820 | 27 | 172 |
| 2143E | *Eucalyptus cladocalyx* | Sugar Gum | $50,360 | 28 | 159 |
| 41 | *Eucalyptus cladocalyx* | Sugar Gum | $49,489 | 28 | 151 |
| 2152 | *Eucalyptus cladocalyx* | Sugar Gum | $48,415 | 31 | 148 |
| 15 | *Ficus macrophylla* | Moreton Bay Fig | $46,944 | 15 | 143 |
| 2144A | *Pinus canariensis* | Canary Islands Pine | $46,552 | 29 | 137 |
| 1880 | *Araucaria bidwillii* | Bunya Pine | $46,188 | 27 | 136 |
| 2141B | *Eucalyptus cladocalyx* | Sugar Gum | $46,177 | 25 | 145 |
| 1201I | *Eucalyptus cladocalyx* | Sugar Gum | $44,231 | 28 | 150 |
| 2146A | *Eucalyptus cladocalyx* | Sugar Gum | $43,834 | 19 | 134 |
| 304 | *Pinus pinea* | Stone Pine | $43,726 | 16 | 133 |
| 183 | *Ficus rubiginosa* | Port Jackson Fig, Rusty Fig | $43,655 | 14 | 134 |
| 2150C | *Eucalyptus cladocalyx* | Sugar Gum | $43,112 | 21 | 132 |
| 2150L | *Eucalyptus cladocalyx* | Sugar Gum | $43,112 | 32 | 132 |
| 1621 | *Eucalyptus microcarpa* | Grey Box | $41,410 | 15 | 154 |
| 2125A | *Eucalyptus cladocalyx* | Sugar Gum | $41,272 | 21 | 137 |
| 1A | *Pinus canariensis* | Canary Islands Pine | $40,216 | 32 | 121 |
| 28 | *Eucalyptus cladocalyx* | Sugar Gum | $40,189 | 26 | 123 |
| 2151 | *Eucalyptus cladocalyx* | Sugar Gum | $39,727 | 24 | 123 |
| 542 | *Pinus halepensis* | Aleppo Pine, Jerusalem Pine | $39,563 | 23 | 122 |
| 101 | *Eucalyptus cladocalyx* | Sugar Gum | $39,135 | 25 | 125 |
| 2149 | *Eucalyptus cladocalyx* | Sugar Gum | $38,944 | 31 | 121 |
| 2150K | *Eucalyptus cladocalyx* | Sugar Gum | $38,548 | 24 | 120 |
| 1208 | *Eucalyptus microcarpa* | Grey Box | $38,156 | 9 | 122 |
| 287 | *Pinus sabiniana* | Digger Pine | $37,966 | 24 | 118 |
| 2126A | *Eucalyptus cladocalyx* | Sugar Gum | $37,748 | 21 | 118 |

# 4. Other Values and Benefits of Waite Arboretum

i-Tree Eco valuations of trees in the urban forest, while useful to compare with other more traditionally valued built assets, inevitably undervalue trees because they do not incorporate the full suite of beneficial services provided by trees such as aesthetics, biodiversity and habitat, higher property values, economic prosperity and enhanced human health and wellbeing[29].

Additional values and benefits of the Waite Arboretum are described below.

## 4.1 Experimental value

### 4.1.1 Diversity of the collection

From the outset, the main aim of the Waite Arboretum was to evaluate the performance of a wide range of species from around the world to assess their habits of growth and suitability to its soils and climate - which is typical of much of settled south-eastern Australia. The Arboretum collection of 2,500 specimens represents 1,000 species in 215 genera and 61 families.

The climate in Adelaide is described as Mediterranean, with hot dry summers and cool wet winters and the Arboretum is dominated by species from homoclimes such as the eastern Mediterranean, Canary Islands, southern California, South Africa and Chile. The main collections are eucalypts (Eucalyptus, Corymbia, Angophora) (360 taxa), oaks Quercus (60 taxa), pears Pyrus (30 taxa), arborescent dragon trees Dracaena (7 taxa), palms and cycads.

Cape Chestnut *Calodendrum capense* #380 – Native to South Africa Photo:J. Gardner

[29] *Tree Ecosystem Services Assessment*, Ridge Park 18 March 2016 Seed Consulting Services

Since 1960 the tree management policy of the Arboretum has been to not water specimens after establishment so the collection demonstrates performance on an annual rainfall of 618 mm without supplementary summer watering for up to 57 years. The best performing species inform more sustainable selection for street and amenity planting. This increasingly valuable information is disseminated in public presentations and publications such as Gardner (2003) and has been facilitated with the formation of TREENET.

### 4.1.2 TREENET

TREENET, founded in 1997, is an independent non-profit national urban tree research and education organisation based at the University of Adelaide's Waite Arboretum and dedicated to improving the urban forest. TREENET advocates and promotes the values of the urban forest, enhances the body of knowledge about street trees, fosters research and tree trials including species of demonstrated merit from the Waite Arboretum www.treenet.org. Annual symposia have been held since 2000 to showcase current research, disseminate information, and foster interdisciplinary collaboration. Proceedings and videos including outdoor presentations held in the Waite Arboretum are available free on line www.treenet.org/symposium-yearly-downloads/

Height: 16 m
DBH: 65 cm
Canopy area: 196 m$^2$
Age: 86 years
Carbon Stored: 1.2 tonne
Pollution removed: 1.5 kg/yr
Structural Value: A$12,147

Crow's Ash or Australian Teak – *Flindersia australis* #184 Photo: J. Gardner

Based on the good performance in the Waite Arboretum TREENET has trialled this species in the City of West Torrens as a street tree in wide verges.

## 4.2 Biodiversity conservation

### 4.2.1 Rare and endangered species and significant trees

Botanic gardens and arboreta play an important role in the *ex situ* conservation of species which are rare and endangered in the wild. The Waite Arboretum collection has 86 species which are listed on the International Union for the Conservation of Nature (IUCN) Red List[30] with a status of Near Threatened or greater. Of these, 28 species have a status of Endangered and six species, including *Pyrus tadshikistanica* and *P. korshinskyi*, are Critically Endangered in the wild. Propagating material from the latter species, grown from seed of know wild provenance, has been distributed to botanic gardens and specialist nurseries. Waite Arboretum also contains native Australian species which are very rare in the wild, As an example, the Small-leaved Tamarind *Diploglottis campbellii* is listed as Endangered in the Environment Protection and Biodiversity Conservation – List of Threatened Species [31].

*Pyrus tadshikistanica* #769B native to Tajikistan Photo: J. Gardner

In addition to species of conservation significance, many specimens and collections in the Waite Arboretum are listed in the National Trusts of Australia 'Register of Significance Trees'. Trees on the Register are deemed to be significant for their scientific, social, historic or aesthetic value[32]. The historic Elm Avenue of 71 English Elm *Ulmus procera*, the avenue of 13 Sugar Gums *Eucalyptus cladocalyx* planted in 1877, and the iconic Dragon Tree *Dracaena draco* arguably qualify for inclusion on the Register.

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30 www.iucnredlist.org
31 www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=21484 [accessed 30/8/17]
32 www.trusttrees.org.au/

Several Waite Arboretum specimens are also listed on the 'National Register of Big Trees – Australian Champion Trees'[33] e.g. Blue Box *Eucalyptus baueriana*, Thozet's Box *Eucalyptus thozetiana*, Slaty Gum *Eucalyptus dawsonii*, Wilga *Geijera parvifolia*, Yellow Bloodwood *Corymbia eximia*, Oriental or Grecian Strawberry Tree *Arbutus andrachne* and Madrone *Arbutus menziesii*.

| | |
|---|---|
| Height: | 11 m |
| DBH: | 110 cm |
| Canopy area: | 549 $m^2$ |
| Age: | 62 years |
| Carbon Stored: | 4.2 tonne |
| Pollution removed: | 2 kg/yr |
| Structural Value: | A$34,439 |

Blue Box *Eucalyptus baueriana* #1507A Photo: J. Gardner

## 4.2.2 Remnant Grey Box

Grey Box (*Eucalyptus microcarpa*) Grassy Woodlands is listed in the Environment Protection and Biodiversity Conservation (EPBC) Act - List of Threatened Ecological Communities[34],and has Endangered status in South Australia. The northwest section of the Arboretum contains five remnant Grey Box which are thought to pre-date European settlement. The site of the Waite Arboretum was formerly within an extensive area of Grey Box woodland, referred to as the Black Forest by early European settlers. In 1998, a project commenced to conserve the indigenous species and reinstate some of the original Grey Box understorey of shrubs and native grasses using seeds sourced from the 121 hectare Waite Conservation Reserve on the University of Adelaide's Waite Campus.

Grey Box – *Eucalyptus microcarpa*
Tree ID #1216
Photo: J. Gardner

| | |
|---|---|
| Height: | 15 m |
| DBH: | 122 cm |
| Canopy area: | 720 $m^2$ |
| Age: | 180+ years |
| Carbon Stored: | 5 tonne |
| Pollution removed: | 2 kg/yr |
| Structural Value: | A$36,972 |

[33] www.nationalregisterofbigtrees.com.au/
[34] environment.gov.au/cgi-bin/sprat/public/publiclookupcommunities.pl [accessed 9/8/17]

## 4.3 Wildlife habitat

Green spaces in cities increase biodiversity. The Waite Arboretum is relatively rich in wildlife for an inner suburban park. The wide range of eucalypts attracts nectar feeding birds like lorikeets. Mature trees, especially eucalypts, provide nesting hollows for birds and possums and roosting places for bats. Pines and araucarias attract large parrots like Sulphur-crested Cockatoos and Long-billed Corellas which descend in huge flocks to feast on the seeds. Galahs, Magpies, White Ibis and Maned Duck are very common. While the number of birds is large the species diversity is low. Domination by a few species of mainly larger more aggressive birds at the expense of other birds is now typical of open parklike areas around Adelaide. This change has occurred in the past 10-30 years[35]. Of the 55 avian species recorded in the Arboretum only 20 are now common. Photographs from the Waite Arboretum - 1,3-6 J. Gardner, 2 Jeff Rose.

1. Tawny Frogmouth and young

2 Rainbow Lorikeet in Hakea

3 Eastern Rosella in watercourse

4 Black Duck and ducklings, Maned Goose and Bronze 'Waterbirds' (sculptor Meliesa Judge)

5 Marbled Gecko

6 Spotted Grass Frog

[35] Penny Paton, personal communication. 15/8/17

Koalas are often seen in the eucalypts. A single Western Grey Kangaroo and Echidna have been sighted in the Arboretum – both most likely strays from the campus Waite Conservation Reserve where they are common. In total seven native mammal, five frog and four reptile species have been recorded. Some of the wildlife recorded in the Waite Arboretum is listed in Appendix 3.

Koala in Blue Gum *Eucalyptus leucoxylon* #1862 JG
Photos from Waite Arboretum –
JG: Jennifer Gardner, EB: Erica Boyle

Fiddler Beetle on *Eucalyptus gillenii* #1961B EB

Caper White Butterfly on Native Caper *Capparis mitchellii* #1152A JG

Waite Arboretum provides habitat for a range of invertebrates including 14 species of butterflies and 14 species of jewel beetles. Dr Katja Hogendoorn, who leads the University of Adelaide's Waite Campus research team investigating native bee behavioural ecology and taxonomy, believes over 100 species of native bees occur in the Waite Arboretum. Native bees are proven to be more efficient pollinators than the introduced European honey bee and are important for agricultural crops. Two native bee 'hotels' have been constructed in the Waite Arboretum to encourage and accommodate the habitat requirements of various species. These features are not only an attraction to visitors, especially children, but a resource for research and educate the public about the ecology of native bees and the beneficial role they play in the environment.

Native Bee Hotel, Waite Arboretum – designed, constructed and maintained by volunteer Terry Langham
Photo: J. Gardner

## 4.4 Research and educational resource

Waite Arboretum is a repository for research collections and cultivars developed in plant breeding programs at the University of Adelaide's Waite Campus. The Arboretum also provides experimental sites and material for research in fields such as plant physiology, phytochemistry, chemotaxonomy, reproductive biology of eucalypts and banksias, entomology, pollination and native bee ecology.

The Arboretum is a resource for education at all levels, fostering a connection with nature and promoting the study of the natural environment. The Arboretum is used by groups across the age spectrum from pre-school children, primary and secondary school students, tertiary students undertaking practical sessions in plant taxonomy, soil science, entomology and horticulture, to retirees attending the University of the Third Age. An educational program linked to the Australian curriculum is currently being developed for primary school children.

Free guided walks and interpretive signs enhance and inform the visitor experience. The free `Waite Arboretum App' for mobile devices was launched in February 2015. The Waite Arboretum App includes general visitor information, has a high resolution aerial image (7 cm) as its map background, includes lists of available 'Themed Walks' with virtual guiding trails highlighting specific trees of the chosen theme / title, and has a location functionality 'Near Me' which displays the user's location and information on every tree within a 22 metre radius, including:

- Scientific name
- Common name
- Family
- Distribution
- Year planted
- Individual tree identification number
- Height and canopy extent (and the shade equivalent in beach umbrellas).

Possibly one of the most useful functionalities is the App's 'Search' option where users can get results under four different fields – Scientific Name, Common Name, Distribution and Tree ID number. The results can be viewed as a list, or displayed on the aerial image/map showing their location enabling the user to navigate to a specific tree/trees of interest.

The 'Waite Arboretum App' also has an image gallery showing tree specimens, sculptures, birds and other wildlife to look out for. The addition of more descriptions and images is in progress and many of the tree descriptions will display the environmental benefits derived from the i-Tree Eco analysis.

## 4.5 Community Engagement

Waite Arboretum is open and free every day of the year from dawn till dusk. Local residents, staff and students of the campus walk through the Arboretum regularly. The amenity and visitor experience has been enhanced with seats, sculptures by local artists, a watercourse and a labyrinth.

There is a strong commitment to raise public and professional awareness of the Arboretum. Community outreach programs include regular free guided walks, booked tours and public presentations. The Friends of the Arboretum Inc. was founded in 1995 to raise awareness and funds to support the Arboretum. There is a vibrant volunteer program with more than 80 participants in the Arboretum and the adjacent themed gardens of the Waite Historic Precinct.

Community groups such as Outdoor Playgroups and Nature Play have organised well-attended events in the Arboretum. These activities for children provide opportunities for exploration, creativity, development of observational skills, building confidence and the use all the senses.

# 5. Recommendations of street and park trees for Adelaide

Trees enhance the vitality and well-being of the community by improving health and productivity, community connection, local commerce, property values, cooler cities, cleaner air, better water management and connection to nature.

Large, long lived, healthy trees provide the greatest environmental services. With increasing urban infill in our major cities and the consequent disappearance or diminution of residential backyards, natural and landscaped parks and street trees contribute to the liveability and aesthetics of our cities.

Table 10 contains recommendations of 40 species for street and amenity planting based on the good performance of mature specimens in the Waite Arboretum, shade / canopy area >140 m, and total environmental benefits (A$) they provide, as ascertained in the i-Tree Ecosystem Analysis - Waite Arboretum Inventory June 2017.

Blue Oak *Quercus douglasii* #281 Photo J. Gardner

**Table 10 - 45 recommended species for street and amenity planting in Adelaide based on mature surveyed trees, with a canopy area > 100 m$^2$ and environmental benefits > A$8.**

Species with shade that are both dense and broad are denoted with an asterisk.

| Scientific name | Common name | Shade | Total EB | Long-lived | Ever-green |
|---|---|---|---|---|---|
| *Acacia pendula* | Weeping Myall, Boree | √* | √ | √ | √ |
| *Acer monspessulanum* | Montpellier Maple | √* | √ | √ | |
| *Afrocarpus falcatus* | Outeniqua, Yellowwood | √* | √ | √ | √ |
| *Angophora costata* | Smooth-barked Apple Myrtle | √ | | √ | √ |
| *Angophora floribunda* | Rough-barked Apple Myrtle | √* | √ | √ | √ |
| *Angophora subvelutina* | Broad-leaved Apple Myrtle | √* | √ | √ | √ |
| *Araucaria bidwillii* | Bunya | √ | √ | √ | √ |
| *Brachychiton x roseus* | Wentworth Flame Tree | √* | √ | √ | |
| *Cedrus atlantica* | Mt Atlas Silver Cedar | √* | √ | √ | √ |
| *Cedrus deodara* | Deodar | √* | √ | √ | √ |
| *Celtis occidentalis* | Sugarberry, Nettle Tree | √ | √ | √ | |
| *Corymbia eximia* | Yellow Bloodwood | √* | √ | √ | √ |
| *Corymbia maculata* | Spotted Gum | √ | √ | √ | √ |
| *Corymbia variegata* | | √ | √ | √ | √ |
| *Dracaena draco* | Dragon Tree | √* | | √ | √ |
| *Eucalyptus baueriana* | Blue box | √* | √ | √ | √ |
| *Eucalyptus camaldulensis* | Red Gum | √ | √ | √ | √ |
| *Eucalyptus largiflorens* | Black Box | √ | √ | √ | √ |
| *Eucalyptus leucoxylon* | Blue Gum | √ | √ | √ | √ |
| *Eucalyptus melliodora* | Yellow Box | √* | √ | √ | √ |
| *Eucalyptus microcarpa* | Grey Box | √ | √ | √ | √ |
| *Eucalyptus populnea* | Poplar or Bimbil Box | √ | √ | √ | √ |
| *Eucalyptus salmonophloia* | Salmon Gum | √ | √ | √ | √ |
| *Eucalyptus sideroxylon* | Mugga, Red Ironbark | √ | √ | √ | √ |
| *Ficus brachypoda* | Small-leaved Rock Fig | √* | √ | √ | √ |
| *Ficus macrophylla* | Moreton Bay Fig | √* | √ | √ | √ |
| *Ficus retusa* | Malay Banyan, Indian Laurel | √* | √ | √ | √ |
| *Ficus rubiginosa* | Rusty Fig | √* | √ | √ | √ |
| *Flindersia australis* | Australian Teak / Crows Ash | √ | √ | √ | semi |
| *Fraxinus pennsylvanica* | Green Ash / Red Ash | √ | √ | √ | |
| *Geijera parviflora* | Wilga | √* | √ | √ | √ |
| *Harpephyllum caffrum* | Kaffir Plum | √* | √ | √ | √ |
| *Juglans hindsii* | Hinds Walnut | √ | √ | √ | |
| *Pinus canariensis* | Canary Island Pine | √* | √ | √ | √ |
| *Pinus pinea* | Stone Pine | √* | √ | √ | √ |
| *Pistachia chinensis* | Chinese Pistachio | √ | √ | √ | |
| *Platanus* x *acerifolius* | Plane Tree | √* | √ | √ | |
| *Quercus agrifolia* | Californian Field / Coast Live Oak | √* | √ | √ | √ |
| *Quercus canariensis* | Canary / Algerian Oak | √* | √ | √ | |
| *Quercus douglasii* | Blue Oak | √* | √ | √ | |
| *Quercus ilex* | Evergreen /Holm / Holly Oak | √* | √ | √ | √ |
| *Quercus lobata* | Valley Oak | √* | √ | √ | |
| *Quercus suber* | Cork Oak | √* | √ | √ | √ |
| *Syzygium paniculata* | Brush Cherry | √* | √ | √ | √ |

# 6. Concluding Remarks

Located only five kilometres from Adelaide CBD, the Waite Campus of the University of Adelaide comprises 200+ hectares where more than 1,500 people work and study in 12 research organisations, centres and nodes. The generous bequest of Peter Waite's estate to the University has resulted in the internationally renowned Waite Research Institute – conducting leading research and delivering world class teaching. The facility is the largest concentration in the southern hemisphere of expertise in the areas of plant biotechnology, cereal breeding, sustainable agriculture, wine, horticulture and land management www.adelaide.edu.au/wri/.

Waite also had the foresight to leave a portion of his estate in perpetuity for a park or garden for the enjoyment of the public. This has resulted in the Waite Arboretum, a significant scientific collection of trees that can be explored and its embodied information accessed worldwide with digital technology. Waite left a much loved and enduring living legacy.

Trees are a dominant element of the Waite Campus, contributing to its strong sense of place and beauty. Through this i-Tree Eco report the authors hope to raise awareness and appreciation of the Waite Arboretum not only for its environmental benefits but also the social, cultural, conservation and educational values it provides. The field data collected for this project not only quantifies the current environmental benefits of the surveyed trees, but will also be valuable baseline data for evaluating the performance and the change in benefits over time with climate change.

> "*…We shouldn't be concerned about trees purely for material reasons, we should also care about them because of the little puzzles and wonders they present us with. Under the canopy of the trees, daily dramas and moving love stories are played out. Here is the last remaining piece of Nature, right on our doorstep, where adventures are to be experienced and secrets discovered."*

'More than just a commodity' from 'The Hidden Life of Trees' by Peter Wohlleben 2015

Outdoor classroom school children under Arboretum Moreton Bay Fig *Ficus macrophylla* #15Photo E. Boyle

## Acknowledgements

The iTree Eco survey would not have been possible without the dedicated efforts of the volunteer survey team, ably led by Erica Boyle for a few hours weekly over 21 months. Other members of the team included Maurico Payan-Luna, Lucas Videla, Muriel Ehbar and Kerrin Fitzgerald. Dr Wayne Harvey is thanked for critically reading the manuscript. Dr Kate Delaporte, Acting Curator Waite Arboretum, provided support to write up this report.

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## Appendix I. i-Tree Eco Model, Field Measurements - Extract from 'i-Tree Ecosystem Analysis, Waite Arboretum Inventory June 2017' pages 21-24.

i-Tree Eco is designed to use standardized field data and local hourly air pollution and meteorological data to quantify urban forest structure and its numerous effects (Nowak and Crane 2000), including:

- Urban forest structure (e.g., species composition, tree health, leaf area, etc.).
- Amount of pollution removed hourly by the urban forest, and its associated percent air quality improvement throughout a year.
- Total carbon stored and net carbon annually sequestered by the urban forest.
- Effects of trees on building energy use and consequent effects on carbon dioxide emissions from power sources.
- Structural value of the forest, as well as the value for air pollution removal and carbon storage and sequestration.
- Potential impact of infestations by pests, such as Asian long horned beetle, emerald ash borer, gypsy moth, and Dutch elm disease.

All field data are collected during the leaf-on season to properly assess tree canopies. Typical data collection (actual data collection may vary depending upon the user) includes land use, ground and tree cover, individual tree attributes of species, stem diameter, height, crown width, crown canopy missing and dieback, and distance and direction to residential buildings (Nowak *et al* 2005; Nowak *et al* 2008).

During data collection, trees are identified to the most specific taxonomic classification possible. Trees that are not classified to the species level may be classified by genus (e.g., ash) or species groups (e.g., hardwood). In this report, tree species, genera, or species groups are collectively referred to as tree species.

Tree Characteristics:

Leaf area of trees was assessed using measurements of crown dimensions and percentage of crown canopy missing.

An analysis of invasive species is not available for studies outside of the United States. For the U.S., invasive species are identified using an invasive species list for the state in which the urban forest is located. These lists are not exhaustive and they cover invasive species of varying degrees of invasiveness and distribution. In instances where a state did not have an invasive species list, a list was created based on the lists of the adjacent states. Tree species that are identified as invasive on the state invasive species list are cross-referenced with native range data. This helps eliminate species that are on the state invasive species list, but are native to the study area.

Air Pollution Removal:

Pollution removal is calculated for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide and particulate matter less than 2.5 microns. Particulate matter less than 10 microns (PM10) is another significant air pollutant. Given that i-Tree Eco analyzes particulate matter less than 2.5 microns (PM2.5) which is a subset of PM10, PM10 has not been separately included in this analysis. PM2.5 is generally more relevant in discussions concerning air pollution effects on human health.

Air pollution removal estimates are derived from calculated hourly tree-canopy resistances for ozone, and sulfur and nitrogen dioxides based on a hybrid of big-leaf and multi-layer canopy deposition models (Baldocchi 1988; Baldocchi *et al* 1987). As the removal of carbon monoxide and particulate matter by vegetation is not directly related to transpiration, removal rates (deposition velocities) for these pollutants were based on average measured values from the literature (Bidwell and Fraser 1972; Lovett 1994) adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere (Zinke 1967). Recent updates (2011) to air quality modeling are based on improved leaf area index simulations, weather and pollution processing and interpolation, and updated pollutant monetary values (Hirabayashi *et al* 2011; Hirabayashi *et al* 2012; Hirabayashi 2011).

User-defined local pollution values are used for international reports. For this analysis, pollution removal value is calculated based on the prices of A$23 per tonne (carbon monoxide), A$4,105 per tonne (ozone), A$612 per tonne (nitrogen dioxide), A$223 per tonne (sulfur dioxide), A$142,612 per tonne (particulate matter less than 2.5 microns).

<u>Oxygen Production:</u>

The amount of oxygen produced is estimated from carbon sequestration based on atomic weights: net $O_2$ release (kg/yr) = net C sequestration (kg/yr) × 32/12. To estimate the net carbon sequestration rate, the amount of carbon sequestered as a result of tree growth is reduced by the amount lost resulting from tree mortality. Thus, net carbon sequestration and net annual oxygen production of the urban forest account for decomposition (Nowak *et al* 2007). For complete inventory projects, oxygen production is estimated from gross carbon sequestration and does not account for decomposition.

<u>Avoided Runoff:</u>

Annual avoided surface runoff is calculated based on rainfall interception by vegetation, specifically the difference between annual runoff with and without vegetation. Although tree leaves, branches, and bark may intercept precipitation and thus mitigate surface runoff, only the precipitation intercepted by leaves is accounted for in this analysis

# Appendix 2 Use of Direct Measures by i-Tree Eco (v6.0)[36]

*Overview of the derived variables and ecosystem services that are estimated by the i-Tree Eco model and how they use the direct measures collected in the field.*

DERIVED VARIABLES

- **Leaf area** is estimated using:
  - Species – to identify shade coefficient
  - Total height – to estimate height of the crown
  - Crown base height – to estimate height of the crown
  - Crown width – to identify crown width dimension
  - Percent crown missing – to modify base leaf area for actual amount present

- **Leaf biomass** is based on leaf area estimates and uses the same direct measures (as described above).

ECOSYSTEM SERVICES

- **Carbon storage** is estimated using:
  - Species – to identify biomass equation
  - Diameter at breast height (DBH) – to calculate tree biomass
  - Total height – to calculate tree biomass
  - Field land use – to assign biomass adjustment factor

  Conditional: For evergreen and palm species, leaf biomass is added to tree biomass so that carbon storage calculations also indirectly use species, total height, crown base height, crown width, and percent crown missing for these species (as described above).

- **Gross carbon sequestration** is estimated using:
  - Species – to identify biomass equations
  - Diameter at breast height (DBH) – to calculate tree biomass
  - Total height – to calculate tree biomass
  - Field land use – to assign biomass adjustment factor
  - Condition (percent dieback) – to adjust growth rates
  - Crown light exposure (CLE) – to adjust growth rates

- **Net carbon sequestration** is estimated using:
  - Species – to identify biomass equations
  - Diameter at breast height (DBH) – to calculate tree biomass
  - Total height – to calculate tree biomass
  - Field land use – to assign biomass adjustment factor
  - Condition (percent dieback) – to adjust growth rates
  - Crown light exposure (CLE) – to adjust growth rates

- **Energy effects** are estimated using
  - Species – to identify leaf class (i.e. deciduous or evergreen)
  - Total height – to identify energy height class
  - Percent crown missing – to adjust energy effect
  - Distance to building - to calculate carbon saved
  - Distance to building - to estimate shade effect
  - Percent tree cover – to determine climate effects
  - Percent building cover – to determine climate effects

[36] https://www.itreetools.org/eco/resources/v6/Ecov6_data_variables_ES_realtionships_05102016.pdf

- **Air pollution removal** is estimated using:
    - Percent tree cover

  Indirect: Air pollution removal estimates use leaf area index (LAI) and percent evergreen which are derived by the i Tree Eco model. LAI is estimated using leaf area and thus air pollution removal is indirectly estimated from species, total height, crown base height, crown width, and percent crown missing (as described above). Percent evergreen is estimated based on the amount of leaf area that is contributed by evergreen species.

- **Avoided runoff** is estimated using:
    - Percent tree cover

  Indirect: Avoided runoff estimates use leaf area index (LAI) which is derived by the i Tree Eco model. LAI is estimated using leaf area and thus avoided runoff is indirectly estimated from species, total height, crown base height, crown width, and percent crown missing (as described above).

- **Transpiration** is estimated using:
    - No Direct Measures

  Indirect: Transpiration estimates use leaf area index (LAI) which is derived by the i Tree Eco model. LAI is estimated using leaf area and thus transpiration is indirectly estimated from species, total height, crown base height, crown width, and percent crown missing (as described above).

- **VOC emissions** are estimated using:
    - Species – to inform genus and base VOC emission rates

  Indirect: VOC emission estimates use leaf biomass which is derived by the Eco model. Leaf biomass is estimated using leaf area and thus VOC emissions are indirectly estimated from species, total height, crown base height, crown width, and percent crown missing (as described above).

- **Compensatory value** is estimated using:
    - Species – to assign species specific factors and taxonomic class
    - Diameter at breast height (DBH) – to calculate trunk size
    - Field land use – to determine location factor
    - Condition (percent dieback) – to adjust value

| | DERIVED VARIABLES | | ECOSYSTEM SERVICES | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **DIRECT MEASURES** | Leaf Area | Leaf Biomass | Carbon Storage | Gross Carbon Sequestration | Net Carbon Sequestration | Energy Effects | Air Pollution Removal | Avoided Runoff | Transpiration | VOC Emissions | Compensatory Value |
| Species | D | D | D | D | D | D | I | I | I | D | D |
| Diameter at breast height (DBH) | | | D | D | D | | | | | | D |
| Total height | D | D | D | D | D | D | I | I | I | I | |
| Crown base height | D | D | C | | | | I | I | I | I | |
| Crown width | D | D | C | | | | I | I | I | I | |
| Crown light exposure (CLE) | | | | D | D | | | | | | |
| Percent crown missing | D | D | C | | | D | I | I | I | I | |
| Condition (crown dieback) | | | | D | D | | | | | | D |
| Field land use | | | D | D | D | | | | | | D |
| Distance to building | | | | | | D | | | | | |
| Direction to building | | | | | | D | | | | | |
| Percent tree cover | | | | | | D | D | D | | | |
| Percent building cover | | | | | | D | | | | | |

| | |
|---|---|
| D | Directly used |
| I | Indirectly used |
| C | Conditionally used |

# Appendix 3 Native Fauna of the Waite Arboretum

| VERTEBRATES | Common Name | Scientific Name |
|---|---|---|
| **MAMMALS** | | |
| | Short-beaked Echidna[1] | *Tachyglossus aculeatus* |
| | Koala | *Phascolarctos cinereus* |
| | Common Brush-tail Possum | *Trichosurus vulpecula* |
| | Common Ringtail Possum | *Pseudocheirus peregrinus* |
| | Western Grey Kangaroo[2] | *Macropus fuliginosus* |
| | Native Water Rat[3] | *Hydromys chrysogaster* |
| | Unidentified bats[4] | |
| **FROGS** | | |
| | Brown Tree Frog | *Littoria ewingii* |
| | Common Froglet | *Crinia signifera* |
| | Eastern Banjo Frog or Pobblebonk | *Limnodynastes dumerilii* |
| | Spotted Grass Frog | *Limnodynastes tasmaniensis* |
| | Painted Frog | *Neobatrachus pictus* |
| **REPTILES** | | |
| | Eastern Blue-tongue Lizard | *Tiliqua scincoides* |
| | Marbled Gecko | *Christinus marmoratus* |
| | Skinks (several) | |
| **BIRDS** | | |
| | Maned Duck (Australian Wood Duck) | *Chenonetta jubata* |
| | Pacific Black Duck & Mallard hybrids | *Anas superciliosa* |
| | Australian White Ibis | *Threskiornis moluccus* |
| | Masked Lapwing | *Vanellus miles* |
| | Crested Pigeon | *Ocyphaps lophotes* |
| | Sulphur-crested Cockatoo | *Cacatua galerita* |
| | Long-billed Corella | *Cacatua tenuirostris* |
| | Yellow-tailed Black Cockatoo[1] | *Calyptorhynchus funereus* |
| | Galah | *Eolophus roseicapilla* |
| | Crimson (Adelaide) Rosella | *Platycercus elegans* |
| | Eastern Rosella | *Platycercus eximius* |
| | Musk Lorikeet | *Glossopsitta concinna* |
| | Rainbow Lorikeet | *Trichoglossus haematodus* |
| | Southern Boobook | *Ninox boobook* |
| | Tawny Frogmouth | *Podargus strigoides* |
| | Laughing Kookaburra | *Dacelo novaeguineae* |
| | Noisy Miner | *Manorina melanocephala* |
| | Australian Magpie | *Gymnorhina tibicen* |
| | Grey Currawong | *Strepera versicolor* |
| | Magpielark | *Grallina cyanoleuca* |
| | Little Raven | *Corvus mellori* |
| | Welcome Swallow | *Hirundo neoxena* |

1 Occasional records, common in nearby Waite Conservation Reserve
2 Single sighting, common in nearby Waite Conservation Reserve
3 Single sighting at the watercourse and burrow in the bank
4 Six species of native bats have been recorded in the nearby Waite Conservation Reserve

| INVERTEBRATES | Common Name | Scientific Name |
|---|---|---|
| **CRUSTACEAN** | Common Yabbie | *Cherax destructor* |
| **BEETLES** | | |
| | Pintail or Tumbling Flower Beetle | *Mordella* sp. |
| | Scarab | *Glycyphana brunnipes* |
| | Buprestid (Jewel Beetle)[1,2] | *Agrilis hypoleucus* |
| | Buprestid (Jewel Beetles)[1] | *Anilara longicollis, A. obscura* |
| | Buprestid (Jewel Beetles)[2] | *Castiarina amplipennis, C. crenata* |
| | Buprestid (Jewel Beetles) | *Cisseus* sp., *Diphucrania modesta* |
| | Buprestid (Jewel Beetle)[1] | *Germarica lilliputana* |
| | Buprestid (Jewel Beetles) [1,2] | *Melobasis fasciata, M. simplex, M. sordida* |
| | Buprestid (Jewel Beetles)[1] | *Pseudanilara piliventris, P. purpureicollis* |
| | Buprestid (Jewel Beetle)[2] | *Selagis auifera* |
| | Buprestid (Jewel Beetle)[1] | *Temognatha lessonii* |
| **BEES & WASPS** | | |
| | Blue Banded Bee | *Amegilla* sp. |
| | Leafcutter Bee | *Megachile* sp. |
| | Masked Bees | *Hylaeus* species |
| | Golden Browed Resin Bee | *Chalicodoma aurifrons* |
| | Resin Bees (several) | *Chalicodoma* species |
| | Wasp Mimic Bee | *Hyleoides concinna* |
| | Homalictus Bees | *Homalictus* species |
| | Cuckoo Wasp | Family Chrysididae |
| | Wasps | *Aulacus* sp & *Pristaulacus* sp. |
| **ANTS** | | |
| | Bull Ant (Inch Ant) | *Myrmecia* sp. |
| | Sugar Ant | *Campanotis* sp. |
| | Meat Ant | *Iridomyrmex pupureus* |
| **BUTTERFLIES & MOTHS** | | |
| | Dainty Swallowtail | *Papilio anactus* |
| | Chequered Swallowtail | *Papilio demoleus* |
| | Caper White | *Belenois java* |
| | Double-spotted Line-blue | *Nacaduba biocellata* |
| | Common Grass-blue | *Zizina labradus* |
| | Marbled Xenica | *Geitoneura klugii* |
| | Common Brown | *Heteronympha merope* |
| | Tailed Emperor | *Polyura pyrrhus* |
| | Meadow Argus | *Junonia villida* |
| | Australian Painted Lady | *Vanessa kershawi* |
| | Yellow or Australian Admiral | *Vanessa itea* |
| | Wanderer*[3] | *Danaus plexippus* |
| | Yellow Banded Dart | *Ocybadistes walkeri* |
| | Rain Moth | *Abantiades marcidus* |
| **OTHER INSECTS** | | |
| | Lantern Fly | *Retinus dilatatus* |
| **SPIDERS** | | |
| | Redback Spider | *Latrodectus hassleti* |
| | Crab Spider | *Stephanopsis* sp. |
| | Huntsmen Spider | *Isopedia woodwardi* |

Buprestid records provided by 1. Dr Peter Lang and 2. Dr Richard Glatz
*Introduced to Adelaide in the mid 1880s. The most common butterfly in the Arboretum