GREEN IS THE NEW GOLD

MONEY DOES GROW ON TREES

Proceedings of the

22nd National Street Tree Symposium

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Contents

INSTITUTIONAL MEMBERS OF TREENET 2021 ... 7

TREENET MANAGEMENT COMMITTEE AND ADVISORY BOARD 2021 ... 9

TREENET INCORPORATED CONSTITUTION ... 11

SPEAKER AND PANELIST PROFILES ... 18

- Professor David Pannell ... 18
- Dr Greg Moore OAM ... 18
- Kirrillie Rowe ... 18
- Darryl Gobbett ... 19
- Rob Bodenstaff ... 19
- Dr Tim Johnson ... 19
- Sam Middleton ... 20
- Natasha Davis ... 20
- Ian Seccafien ... 20
- Ben Seamark ... 20
- Dr Samuel Holt ... 21
- Thami Croeser ... 21
- Dr Natasha Pauli ... 21
- Steven Pearce ... 21

GREEN IS THE NEW GOLD: THE VALUE OF URBAN TREES ... 22

- Introduction ... 22
- Values ... 22
- The value of urban trees ... 22
- Techniques for monetising values ... 23
- Evidence ... 24
- Conclusion ... 25
- References ... 25

DEVELOPING AN AUSTRALIAN STREET TREE COST MODEL ... 26

- Abstract ... 26
- Introduction ... 26

PUTTING A DOLLAR VALUE ON URBAN FOREST BENEFITS 35
Abstract 35
Introduction 35
Method 36
Literature Review 37
General reviews of non-market values 37
Values of specific benefits and services 38
Aesthetic/amenity values 39
Shading and temperature reduction 39
Mitigation of the Urban Heat Island effects 39
Storm water management 40
Carbon sequestration 40
Improved air quality 40
Biodiversity 40
Human productivity 41
Crime 41
Coastal storm protection 41
Tourism and recreation 41
General 41
Monetised health values 42
Mental health benefits 42
Increased physical activity 42
Cardiometabolic diseases 42
Air pollution 43
Dementia 43
Attention deficit and hyperactivity disorder (ADHD) 44
Birth weight 44
Sleep 44
Non-monetised health values 44
Human health 44
Pollinators 45
Biodiversity 45
Microplastics 45
Reducing wind velocity 46
Emerging values 46
Conclusion 46
References 47

INVESTING IN TREES: IT'S A NO BRAINER! 58
Abstract 58
Introduction 58
Trees are appreciating assets which deliver benefits of substantial value 58
What value would we put on an avenue? 60
Investing successfully in trees 61
Adelaide Street, Brisbane, Queensland 61
Victoria Avenue, Chatswood, New South Wales 62
Bank Street, Adelaide, South Australia 63
Successful investment in trees and associated assets 64
Investing in trees and avenues for the future 65
Conclusion 68
References 70

CELEBRATING OUR ICONIC RED GUMS THROUGH THE 'ECO-ARTS RED GUM TRAIL' 71
Abstract 71
Introduction 71
Why Red Gums? 72
Conclusion 75

DATA DOES GROW ON TREES (FORESTREE) 76
Introduction 76
Why Forestree was developed for Councils 76
Marion Tree Interactive (Marion - A Green City) 77
Power BI (Data Analysis/Dashboards) 78
Conclusion 79

GREENER, COOLER AND MORE SUSTAINABLE COMMUNITIES: MANAGING THE URBAN FOREST INTO THE FUTURE USING GEOSPATIAL DATA. 81
Abstract 81
1, Introduction 82
2. Project Datasets 83
3. Case Study 1 – Tree Canopy Coverage Benchmark, Metropolitan Adelaide, 2018/19 84
3.1 Project Summary 84
3.2 Methodology 84
3.3 Results 85
3.4 Key Project Outcomes 86

4. Case Study 2 – City-wide plantable space assessment, Metropolitan Adelaide, 2018/19 87
4.1 Project Summary 87
4.2 Methodology 88
4.3 Results 89
4.4 Key Project Outcomes 90
5. Case Study 3 – High resolution tree canopy change detection and classification, City of Unley 91
5.1 Project Summary 91
5.2 Methodology 91
5.3 Results 91
5.4 Key Project Outcomes 92
6. Conclusions 93
Acknowledgements 94
References 94

FROM PARKING TO PARKS: THE BENEFITS OF PLANTING TREES IN MELBOURNE'S THOUSANDS OF REDUNDANT CAR PARKING SPACES 98
Abstract 98
Overview 98

SHAPING THE LIVING ARCHITECTURE OF THE STREET: UNDERSTANDING PERTH'S NATIVE VERGE GARDEN REVOLUTION 99
Abstract 99
Introduction 99
Methods and results 101
Social and ecological values of verge gardens 101
Verge garden policy audit 103
Mapping verge garden knowledge networks 103
Key findings 105
Acknowledgements 105
References 106

THE TREE PROJECTS 107

INSTITUTIONAL MEMBERS OF TREENET 2021

ASSOCIATIONS

Council Arboriculture Victoria

Institute of Australian Consulting Arboriculturists

Greenlife Industry Australia

Queensland Arboricultural Association Inc.

Victorian Tree Industry Organisation

GOVERNMENT

Albury City Council

Alexandrina Council

Berri Barmera Council

Brisbane City Council

Campbelltown City Council

City of Adelaide

City of Belmont

City of Burnside

City of Canning

City of Charles Sturt

City of Greater Geelong

City of Holdfast Bay

City of Marion

City of Melbourne

City of Melville

City of Mitcham

City of Norwood Payneham & St Peters

City of Onkaparinga

City of Port Adelaide Enfield

City of Sydney

City of Unley

City of Tea Tree Gully

City of West Torrens

Glen Eira City Council

Green Adelaide

Hume City Council

Inner West Council

Ipswich City Council

Lake Macquarie City Council

Maribyrnong City Council

Moreland City Council

Mount Barker District Council

Newcastle City Council

National Capital Authority

Office for Design & Architecture SA

Toowoomba Regional Council

Transport Canberra and City Services

Wagga Wagga City Council

Whyalla City Council

Yarra Ranges Council

CORPORATE

- Active Green Services
- Active Tree Services
- ArborCarbon
- Arbor Centre
- Arborgreen
- Arbor Operations QLD Pty Ltd
- Botanix Plant Supply Pty Ltd
- Citygreen
- C&R Ryder Consulting
- Classic Tree Services
- DNA Training Solutions
- Enspec Risk & Environment
- Forestree
- Greenwood Consulting
- Homewood Consulting
- Metro Trees
- Mt William Advanced Tree Nursery
- Natural Growth Partners
- Plants Direct Australia
- Project Green
- Quantified Tree Risk Assessment Limited (QTRA)
- Remote Area Tree Services
- Sevron Environmental Contractors
- Space Down Under
- Speciality Trees Pty Ltd
- Terra Cottem Australasia Pty Ltd
- The Tree Company
- Tree Dimensions
- Urbanvirons Group Pty Ltd
- Verve Projects

Click here to visit the TREENET website to find out more about our Institutional Members

TREENET MANAGEMENT COMMITTEE AND ADVISORY BOARD 2021

TREENET MANAGEMENT COMMITTEE

Chairperson:	Dr Lyndal Plant
Director:	Glenn Williams (ex officio)
Treasurer:	Darryl Gobbett *(ex officio)*
Members:	David Lawry OAM
	Dr Greg Moore OAM
	Dr Kate Delaporte
	Dr Tim Johnson
	Cameron Ryder
	Rob Bodenstaff
	Geoffrey Nugent

TREENET ADVISORY BOARD

Glenn Williams	Director TREENET	SA
David Lawry OAM	Founder, TREENET & Avenues of Honour / Space Down Under	SA
Darryl Gobbett	Honorary Treasurer TREENET / Avenues of Honour Project	SA

Educational and Research Institutions

Prof Chris Daniels	CEO, Koala Life; Chair Green Adelaide Landscape Board	SA
Dr Kate Delaporte	Curator, Waite Arboretum, TREENET Management Committee	SA
Dr Greg Moore OAM	Research Assoc. Burnley School of Resource Management & Geography, Chair, TREENET Management Committee	VIC
Dr Dean Nicolle OAM	Director, Currency Creek Arboretum	SA
John Zwar	Australian Inland Botanic Garden	SA
Geoffrey Nugent	Senior Lecturer, Ryde TAFE	NSW

Nursery Industry

John Fitzgibbon	Metro Trees	VIC
Hamish Mitchell	Speciality Trees	VIC

Community

Spencer Brown	Avenues of Honour, France	France
Michael Rabbitt	Avenues of Honour, France	SA

Landscape Architects and Urban Planners

Michael Heath	Chair, National Trust SA Significant Tree Team	SA

Civil Engineers

Russell King Board	Australian Road Research SA	

Arboricultural, Horticultural, Media & Allied Professions

Dr Lyndal Plant	Lyndal Plant Urban Forester, Chair TREENET	QLD
Jan Allen	Terra Ark	QLD
Peter Bishop	Bunya Solutions	QLD
Rob Bodenstaff	Arbor Centre, TREENET Management Committee	WA
David Galwey	Tree Dimensions	VIC
Ben Kenyon	Homewood Consulting	VIC
Phillip Kenyon	Kenyon's Quality Tree Care	VIC
Cameron Ryder	C & R Ryder Consulting, TREENET Management Committee	VIC
Mark Willcocks	Active Tree Services; Avenues of Honour	NSW
Sue Wylie	Tree Talk Arboricultural Consulting	NSW
James Smith	fauNature	SA
Dr Josh Byrne	Josh Byrne & Associates	WA
Sophie Thomson	Sophie's Patch	SA
Geoffrey Fuller	Greenlife Industry Australia (SA)	SA
Jason Summers	Remarkable Trees	VIC

Local Governments

Dr Tim Johnson	City of Mitcham	SA
Christopher Lawry	Mount Barker District Council	SA
Karen Sweeney	City of Sydney	NSW
Vic Bijl	City of Belmont	WA
Ian Seccafien	City of Marion	SA

TREENET INCORPORATED CONSTITUTION

1. NAME

The name of the Association is "TREENET Incorporated"

2. DEFINITIONS

2.1 "The Act" means the Associations Incorporations Act 1985.

2.2 "Association" means the above named Association.

2.3 "Management Committee" means the committee referred to in Rule 11.

2.4 "Advisory Board" means the Board referred to in Rule 12.

3. VISION AND AIMS

3.1 Vision

The vision of the Association is to enhance the role of trees in the urban forest and to engage the community in this endeavour.

3.2 Aims

The aims of the Association are:

3.2.1 To develop and maintain an interactive web application to facilitate the exchange of information relating to urban forests.

3.2.2 To promote research and education relating to urban forests including holding symposia.

3.2.3 To broaden the body of knowledge that exists about street trees and foster research, distribute applicable information, facilitate cooperation and enlist community support concerning the protection, preservation and enhancement of the urban forest.

3.2.4 To establish and maintain a public fund to be called *TREENET Fund* for the specific purpose of supporting the environmental purposes of TREENET Inc. The Fund is established to receive all gifts of money or property for this purpose and any money received because of such gifts must be credited to its bank account. The Fund must not receive any other money or property into its account and it must comply with subdivision 30-E of the Income Tax Assessment Act 1997.

4. POWERS

The Association shall have all the powers conferred by Section 25 of the Act.

5. MEMBERSHIP

5.1 Membership

When an organisation or person has agreed to become a member of the Association and has paid the Association's membership fee where it applies, then that organisation or person will be admitted to membership pursuant to the Constitution, and their name shall be entered in the Association's Register of Members.

5.2 Classes of Member

There shall be five classes of member:

5.2.1 Management Committee Member

This class shall consist of all members of the Management Committee as described in Rule 11.1. Management Committee Members will have the right to receive notice of and attend all meetings.

5.2.2 Advisory Board Member

This class shall consist of natural persons who have been invited by the Management Committee to be on the Advisory Board and agreed. Advisory Board Members will have the right to receive notice of, and attend, the Annual General Meeting and other General Meetings as called. The term of appointment will be for the calendar year.

5.2.3 Associate Member

This class shall consist of natural persons who register an interest in joining the Association and who subscribe to the aims of the Association.

5.2.4 Institutional Member

This class shall consist of research and educational institutions, government bodies, businesses and associations who are financial members. Institutional Members will have the right to receive notice of, and attend, the Annual General Meeting and other General Meetings as called.

5.2.5 Honorary Life Member

This class shall consist of natural persons who have been granted Honorary membership at the discretion of the Management Committee. Honorary Life Members will have the right to receive notice of and attend the Annual General Meeting and other General Meetings as called.

5.3 Votes

Members may exercise the following voting entitlements:

5.3.1 Management Committee Member – 1 vote

5.3.2 Advisory Board Member – 1 vote

5.3.3 Associate Member – members of this class shall have no votes

5.3.4 Institutional Member – financial members – 1 vote by representation or proxy

5.3.5 Honorary Life Member – 1 vote

5.4 Register of Members

A Register of Members shall be kept which contains the name, postal or electronic address, class of membership and subscription details of each Member and the date of joining the Association.

5.5 No Transfer of Rights

The rights and privileges of a Member shall not be transferable and shall cease upon such an organisation or person ceasing to be a Member.

6. MEMBERSHIP FEES

The Management Committee shall from time to time set the terms and conditions of membership fees, if any, for the different classes of membership.

7. CESSATION OF MEMBERSHIP

Membership may cease by resignation, expulsion or non-payment of fees.

7.1 Resignation

Members shall cease to be a member by notifying the Association by whatever means the Management Committee might direct from time to time.

7.2 Expulsion

If any Member wilfully refuses or neglects to comply with the provisions of the Constitution, or is guilty of any conduct which in the opinion of the Management Committee is unbecoming to a Member or prejudicial to the interests of the Association, the Committee shall have the power to expel the member from the Association PROVIDED THAT at least one month before the Committee Meeting at which a resolution for the Member's expulsion is to be considered, the Member shall have been given notice of such meeting and what is alleged against them and of the intended resolution for their expulsion, and they shall at such meeting and before the passing of such resolution have had an opportunity to give oral or written explanation for their defence.

7.3 Non-payment of Fees

If a Member has not paid fees as agreed in the terms and conditions and has been notified in writing by the Association of this failure, then the Member shall cease to be a Member of the Association unless the prescribed fee is paid by the date as notified.

8. PROPERTY AND FINANCE

8.1 The funds and other property of the Association shall be managed and controlled by the Management Committee and shall be used only for the vision and aims of the Association.

8.2 All cheques, negotiable instruments and orders drawn by the Association shall be signed by two persons designated by the Management Committee.

8.3 Subject to Rule 8.1, the surplus funds of the Association may be invested in such manner as the Management Committee sees fit, except direct equities.

8.4 The accounts of the Association shall be audited annually.

8.5 The financial year of the Association shall be from 1 July to 30 June.

8.6 The Association shall prepare financial accounts at the end of each financial year.

9. NOT-FOR -PROFIT

The assets and income of the Association shall be applied solely in furtherance of its above-mentioned vision and aims and no portion shall be distributed directly or indirectly to the members of the Association except as bona fide compensation for services rendered or for reimbursement for expenses incurred.

10. MEETINGS OF THE ASSOCIATION

10.1 The Annual General Meeting shall be held at such time as the Management Committee shall determine.

10.2 Any Motion that any voting Member proposes to move at the Annual General Meeting including a proposal to alter the Constitution shall be given in writing to the Management Committee at least four weeks before the meeting.

10.3 At least 21 days before the Annual General Meeting or any other General Meeting, notice shall be given by written or electronic form sent to all members of the Association entitled to vote, but any accidental omission to give notice to any voting member shall not invalidate the meeting.

10.4 At the Annual General Meeting, ordinary business shall be the presentation of the audited financial accounts, election of the Management Committee and the appointment of an auditor.

10.5 Each voting member present shall be entitled to one vote. In case of an equality of votes, the Chair shall have a second or casting vote.

10.6 A Special General Meeting may be requested by ten voting members presenting an agenda to the Management Committee, the agenda being signed by all ten members. The Management Committee must within 14 days give notice of a Special General Meeting to be at least 21 days from the notice date.

The Special General Meeting will be limited to the agenda items plus other items of which the Committee gives notice. Once the agenda items have been resolved by consensus, resolution or vote they cannot be used again to call a Special General Meeting for 52 weeks from the meeting date.

10.7 An Advisory Board Member shall be entitled to appoint in writing a natural person, who is also an Advisory Board Member of the Association, to be his or her proxy, and to vote on his or her behalf at any general meeting of the Association.

11. MANAGEMENT COMMITTEE

11.1 Membership of the Management Committee

The Management Committee will comprise six elected members drawn from education and research, business and government sectors of the community and three *ex officio* members as follows:

11.1.1 An academic from a tertiary educational institution

11.1.2 A member of Local Government

11.1.3 Four other members

11.1.4 The Director of Waite Arboretum will be a member *ex officio* and may also represent The University of Adelaide with consent from the University

11.1.5 The Directors of TREENET and the Treasurer of TREENET will be members *ex officio*.

11.2 Elections

11.2.1 The elected members of the Management Committee shall be elected annually by voting members of the Association at the Annual General Meeting.

11.2.2 Where the number of candidates for membership of the Management Committee exceeds the maximum number, elections shall be held by secret ballot of members at the Annual General Meeting entitled to vote. In the case of an equality of votes, the Chair shall have a second or casting vote.

11.2.3 The nomination of a candidate for membership of the Management Committee must be in writing, signed by a proposer (who must be an Advisory Board member) and by the nominee. The nomination must be delivered to the Director of the Association before such time as the Management Committee shall determine.

11.2.4 Subject to Rule 11.1, the Management Committee shall have the power to co-opt further Committee members and to fill casual vacancies.

11.3 Office Bearers

The Office Bearers of the Association shall be:

Chair

Directors & Public Officer *ex officio*

Treasurer *ex officio*

11.4 Procedures Generally

The Management Committee may meet in person or confer by video or telephone conferencing, email or by other electronic means for the dispatch of business and subject to the Constitution, otherwise regulate its meetings as it thinks fit.

11.5 Calling of Committee Meetings

11.5.1 The Management Committee shall meet or confer at least four times per year as described in 11.4. Notice of the meeting or conference shall be given in writing to each Committee Member.

11.5.2 The position of any Committee member absent for three consecutive meetings or conferences without leave of absence shall automatically become vacant. Acceptance of an apology shall be deemed grant of such leave.

11.6 Chair

The Chair shall take the chair at meetings. In his or her absence, the Committee shall appoint a member of the Committee to chair the meeting.

11.7 Decisions of Questions

Questions arising before a meeting of the Committee shall be decided by a majority vote. In case of an equality of votes, the chair shall have a second or casting vote.

11.8 Reporting

The Management Committee shall be responsible to the Association and shall present an annual report, including the audited financial accounts, to each Annual General Meeting.

11.9 Auditor

The Management Committee shall appoint an auditor of the Association, who will hold office until the next Annual General Meeting of the Association.

12. ADVISORY BOARD

12.1 There shall be an Advisory Board of the Association.

12.2 The Advisory Board will comprise persons who are competent and willing to provide advice to the Association in their individual areas of expertise, and to liaise with other bodies and institutions for the purpose of facilitating the flow of information between the Association and those other bodies and institutions, and facilitating the implementation of projects which the Association undertakes in furtherance of its aims.

12.3 Members of the Advisory Board shall have no power or authority to represent the Association in any dealings between the Association and third parties.

12.4 The Advisory Board shall meet at such times and places as the Management Committee shall determine.

12.5 The Chair of the Management Committee will take the chair at meetings of the Advisory Board.

13. QUORUMS

13.1 The quorum at general meetings of the Association shall be six members entitled to vote.

13.2 The quorum at Management Committee meetings shall be three members.

14. AUTHORITY TO ENTER INTO CONTRACTS OR AGREEMENTS

The Association shall not be committed to any binding contract or Agreement except pursuant to a resolution of the Management Committee and the instrument shall be signed by at least two members of the Committee.

15. DISSOLUTION

15.1 The Association shall be dissolved if a resolution to this effect is carried by a three-quarters majority voting in person or by proxy at a general meeting, 21 days' notice of the proposed resolution having been given to all members entitled to vote.

15.2 In the event of the Association being dissolved, the amount that remains after such dissolution and the satisfaction of all debts and liabilities shall be transferred to the University of Adelaide, for expenditure on the Waite Arboretum only.

16. ALTERATION TO THE CONSTITUTION

This Constitution may be altered by resolution of a majority of three-quarters of members entitled to vote and who cast a vote in person or by proxy at a general meeting. Written notice of amendments shall be posted to all members entitled to vote at the same time as the notice of the meeting.

17. REQUIREMENTS OF THE PUBLIC FUND

The organisation must inform the Department responsible for the environment as soon as possible if:

- it changes its name or the name of its public fund; or
- there is any change to the membership of the management committee of the public fund; or
- there has been any departure from the model rules for public funds set out in the Guidelines to the Register of Environmental Organisations.

18. MINISTERIAL RULES

The organisation agrees to comply with any rules that the Treasurer and the Minister with responsibility for the environment may make to ensure that gifts made to the fund are only used for its principal purpose.

19. CONDUIT POLICY

Any allocation of funds or property to other persons or organizations will be made in accordance with the established purposes of the organisation and not be influenced by the preference of the donor.

20. WINDING-UP

In case of the winding-up of the Fund, any surplus assets are to be transferred to another fund with similar objectives that is on the Register of Environmental Organizations.

21. STATISTICAL INFORMATION

Statistical information requested by the Department on donations to the Public Fund will be provided within four months of the end of the financial year.

An audited financial statement for the organisation and its public fund will be supplied with the annual statistical return. The statement will provide information on the expenditure of public fund monies and the management of public fund assets.

22. RULES FOR THE PUBLIC FUND

22.1 The objective of the fund is to support the organisation's environmental purpose.

22.2 Members of the public are to be invited to make gifts of money or property to the fund for the environmental purposes of the organisation.

22.3 Money from interest on donations, income derived from donated property, and money from the realisation of such property is to be deposited into the fund.

22.4 A separate bank account is to be opened to deposit money donated to the fund, including interest accruing thereon, and gifts to it are to be kept separate from other funds of the organisation.

22.5 Receipts are to be issued in the name of the fund and proper accounting records and procedures are to be kept and used for the fund.

22.6 The fund will be operated on a not-for-profit basis.

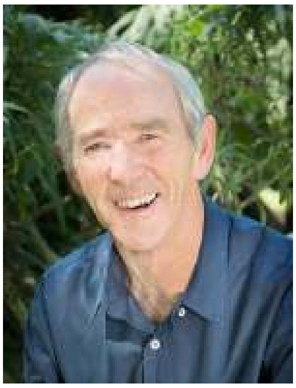
22.7 A committee of management of no fewer than three persons will administer the fund. The committee will be appointed by the organisation. A majority of the members of the committee are required to be 'responsible persons' as defined by the Guidelines to the Register of Environmental Organizations.

SPEAKER AND PANELIST PROFILES

Professor David Pannell

David Pannell is Professor of Agricultural and Resource Economics, University of Western Australia; Director, Co-Centre for Environmental Economics and Policy; ARC Federation Fellow (2007-2012); Distinguished Fellow and past president of the Australian Agricultural and Resource Economics Society; Fellow of the Academy of Social Sciences in Australia; and a Director of Natural Decisions Pty Ltd. His research includes the economics of urban greening; economics of land, water and nature conservation; environmental policy; and behaviour change to deliver environmental benefits. David has won awards for his research in the USA, Australia, Canada and the UK, including the 2009 Eureka Prize for Interdisciplinary Research.

Dr Greg Moore OAM



Apart from a general interest in horticultural plant science, revegetation and ecology, Greg has a specific interest in all aspects of arboriculture, which is the scientific study of the cultivation and management of trees. He has contributed to the development of Australian Standards in pruning, protection of trees on development sites and amenity tree evaluation and has been a major speaker at conferences in Australia, China, Israel, Hong Kong, USA, France and New Zealand. He was the inaugural president of the International Society of Arboriculture, Australian Chapter. He has been a regular on Melbourne radio, particularly with ABC 774 and 3AW.

He has been a member of the National Trust of Victoria's Register of Significant Trees since 1988 and has chaired the committee since 1996. Greg was on the Board of Greening Australia (Victoria) 1988 - 2012. He has been on the board of TREENET (chair 2005-2019) since 1999 and has been on the Board of Sustainable Gardening Australia since 2002. He was a ministerial nomination for the Trust for Nature from 2009 to 2017 and for Yarra Park from 2010 - 2020. He has also served on a number of industry and TAFE sector committees, especially those that deal with curriculum and accreditation matters.

He continues to pursue an active research profile in any matters that relate to trees in the urban environment and revegetation. He has written three books, seven book chapters and has had some 180 papers and articles relating to tree biology and management published. He was awarded an OAM in 2017 for services to the environment, particularly arboriculture.

Kirrillie Rowe

Kirrilie Rowe has recently completed a PhD in renewable energy for residential precincts. Her research has given communities a way forward when trying to maximise use of their own renewable energy. However, her interest extends beyond electricity, to encompass all ideas which create a socially and environmentally sustainable place to live. To this end, she undertook an internship with TREENET, looking at the financial benefit of services provided by urban trees, as she understands the integration of greenspace in the urban environment is fundamental to a healthy community. Kirrilie's working life has included working as a hydrogeologist with consultancies and government departments in South Australia, and later involvement with a company undertaking solar installations. Her aim is to combine all she has learnt and undertake further research into the potential benefits of alternative urban forms. To understand more about Kirrilie's work, you can access her TEDx at:

www.youtube.com/watch?v=QwLT7KVvyvA

Darryl Gobbett

Darryl has spent over 45 years in the public and private sectors, serving in senior management and economic and financial advisory roles.

Darryl continues to provide regular commentary on the South Australian economy.

He is a Visiting Fellow at the SA Centre for Economic Studies at the University of Adelaide; a Graduate of the Australian Institute of Company Directors; a Director of Minda Inc., South Australia's largest Not for Profit cognitive disability services provider; and a Director of a number of startup businesses.

Darryl has been the Honorary Treasurer at TREENET since 2013 and enjoys his volunteer work in community and environmental services, including 30 years as a Grower Member of Trees For Life

Rob Bodenstaff

Rob has spent over 30 years pursuing the better management and utilisation of trees in Western Australia's diverse urban environs.

Seeking and influencing others to engage in achieving better outcomes for urban trees, has been the driver for him. This has led to the creation of multi-disciplined expertise in arboricultural consultancy, tree canopy management, root zone management, veteran and icon tree management and civic tree farming, as well as being a recognised leader in mature tree transplanting in Australia and Internationally.

Rob's firsthand experience in developing world leading tree transplanting techniques for mature trees within urban precincts, has bought to light many aspects of our native tree root systems that challenge common literature on the subject and also challenges the way we often manage tree roots in Western Australia's endemic sands and soils.

His experience and the ongoing investigations, trials, projects and research is helping us discover better ways to successfully engineer trees into the unique built urban environment within Perth's coastal sands and broader regions; and that may well have application elsewhere.

Dr Tim Johnson

Tim is an arborist, green engineer, conservationist and researcher who works to better connect urban communities with nature in their gardens, streets and parks. Tim's interests focus on green engineering design to support trees and urban vegetation so interactions between plants, infrastructure, water and soil can deliver maximum community and environmental benefit. Through his role as Sustainable Infrastructure Engineer working for the City of Mitcham in South Australia, Tim leads research based on experiments designed into working infrastructure in the public realm.

Current research projects include investigating the effects of stormwater harvesting on transpiration rates in urban trees, the capacity of urban soil to retain stormwater, and the effects of stormwater infiltration on reactive soil. Tim is currently supervising two PhD students who are researching the stormwater management benefits of dispersed, small-scale infiltration devices and the climate moderation impacts of stormwater infiltration into tree root zones.

Tim serves on the Advisory Board and Management Committee of TREENET Incorporated and is a member of several industry groups including the Institute of Public Works Engineering Australasia, Arboriculture Australia, the International Society of Arboriculture and the South Australian Local Government Urban Forest Alliance. He is an Industry Adjunct at the University of South Australia-STEM and an Adjunct Lecturer at Flinders University. He has served on the Significant Tree Committee of the National Trust of South Australia (2002 – 2012) and the South Australian Urban Forest Biodiversity Program (1997–2006).

Sam Middleton

Sam's love of Red Gums originated in the landscapes of the Adelaide Hills, but it was a move to South-west Victoria and a 'life amongst the Reds' which inspired the founding of 'Celebrating Red Gums'. Sam's background in varied finance and administration roles within the agricultural, rural landscape and emergency services sectors enables her to comprehensively support the 'platform of opportunity' which the initiative extends to the wider community.

Natasha Davis

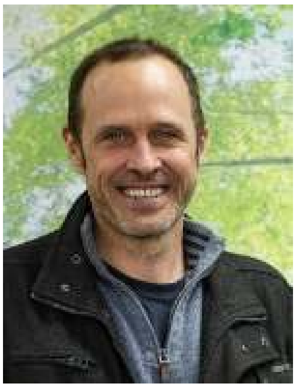
Natasha is the CEO of Trees For Life and has a deep passion for Australian landscapes. She has worked in a diverse range of roles in politics, business, government and the community sector, all with a focus on creating a fairer society that operates in greater harmony with the natural world. She is also a mum and spends as much time in nature as possible.

Ian Seccafien

Ian Seccafien is the Coordinator Arboriculture at the City of Marion. With 20+ years of Local Government experience, previously as the Senior Urban Forest Officer at City Of Onkaparinga he provides strategic and operational coordination to manage and grow Marion's urban forest.

Starting his career as a Horticulture (Arboriculture) apprentice and working out in the field for over a decade, his experience and knowledge lead him into a tree assessment and contract supervision officer role. In recent years this has evolved into a strategic management role, working closely with his field teams to deliver service level improvements and strategic targets /actions relating to urban forestry management for the council.

Ben Seamark



Ben Seamark is an Environmental Manager and Consulting Arborist and has spent over 25 years working with trees. In 2018 Ben was awarded TREENET's Leadership in Urban Forestry. He studied at Flinders University and the University of Adelaide and Brookway Park school of Horticulture. Ben is the Co-founder of Forestree Australia, a tree management software system built to help cities plan, manage and grow urban trees. Forestree was launched in 2020, and in this short time has seen significant adoption by Council arborists who recognise a need for specialised software designed to manage not just trees, but the whole of life supply chain associated with urban forestry management. Ben's work and life experiences have generated a passion for the tree industry and the role trees play in society and community, his other areas of interest include Environmental Economics, Information Technology and Horticultural Science

Dr Samuel Holt

Sam is currently part of the Research & Development Team at Aerometrex, working closely with various stakeholders across the government & private sectors.

Sam has a strong foundation in Earth Sciences and a keen interest in the acquisition and processing of 3D geospatial datasets. He completed a PhD in Physical Volcanology and Bachelor of Science with Honours in Geology and Geophysics before pursuing his keen interest in remote sensing of the natural and urban environment by completing his Graduate Diploma in GIS & Remote Sensing.

He is passionate about building actionable information and solutions using geospatial data to enable environmental management experts and policymakers to build community resilience to a wide range of environmental hazards.

Over the past year, Sam has led the development of Airborne LIDAR-derived methodologies aimed at quantitative modelling vegetation within the urban environment, with the goal of enabling all levels of government to work towards more sustainable communities.

Thami Croeser

Thami is an urban planner and spatial analyst, working at RMIT’s Centre for Urban Research. Thami works with cities around the world to prepare plans for urban green infrastructure in his role on the EU Urban GreenUp project. His particular interest is in helping cities find space for trees and greenery in their streets.

Dr Natasha Pauli

Natasha is a Senior Lecturer in Geography at the University of Western Australia, in the School of Agriculture and Environment and School of Social Sciences. Natasha’s research focusses on human-environment interactions. With a broad range of experiences across the biological and social sciences, she is passionate about finding opportunities for conserving and increasing biodiversity in urban, agricultural and natural settings. Prior to becoming an academic, Natasha has also worked in environmental consulting, state government, and the NGO sector.

Steven Pearce

Steve along with his wife Dr Jen Sanger has travelled to many of the world’s big tree environments with the goal of exploring, climbing and photographing these monster trees. He has approached big trees and tree climbing from an exploratory artistic perspective and is dedicated to sharing the imagery and stories of these trees. In 2020 Steve launched the Tasmanian Big Tree Register and in 2021 released his film The Tasmanian Big Tree Hunters. He plans on revealing a 2m high print of his latest "tree portrait", a snow covered 76m *Eucalyptus obliqua* deep in the Florentine Valley of Tasmania at the TREENET Symposium.

GREEN IS THE NEW GOLD: THE VALUE OF URBAN TREES

Professor David Pannell

University of Western Australia

Introduction

Urban trees and other vegetation are valuable to the community although most of the benefits they generate are not financial. They provide attractive spaces for recreation and relaxation, thereby contributing to health and wellbeing; they provide habitat for wildlife; they provide some mitigation of urban heat; they sequester carbon; and so on.

Environmental economists are interested in the value of trees and have made various efforts to quantify this value. What I mean by "value" in that sentence is the importance that people place on trees. The value can include financial and non-financial aspects, but one of the aims of environmental economists is to be able to express all aspects of the value in monetary-equivalent terms.

Values

The way that economists approach value is very much through a human lens. The values might relate to benefits to non-human life, but the values we measure reflect how people feel about those benefits. Some people believe that non-human species have intrinsic values, independent of humans, but we don't know how to quantify such values, and in any case, there is a diversity of views about this in the community. In practice, we observe that some people hold very strong environmental preferences while others are largely indifferent or oblivious to the environment. Economists do not pass judgement about which view is correct – they aim to measure the diversity of values and how frequently different values occur in the community.

The most common way of representing an individual's monetary-equivalent value for an environmental benefit (or environmental good) is their "willingness to pay" for the good. This is the highest price that the individual would be willing pay and still voluntarily purchase the good, assuming that the good was only able to be acquired by purchasing it. The attraction of this way of measuring the benefit is that it quantifies the trade-offs that people are prepared to make between the environmental good and other goods. Their willingness to pay for an environmental good indicates that they would be willing to give up other goods to that monetary value in order to obtain the good.

The value of urban trees

As noted earlier, trees generate benefits of various types, including for health, recreation, water quality, heat mitigation and biodiversity. The value of a tree is the sum of the values of these component benefits.

The magnitudes of these benefits is highly context-specific. It depends on factors such as:

- The tree's size and shape.
- The tree's location – in a back yard, on a front verge, in a park, by a roadside, in a carpark, etc.
- The availability of substitutes – an additional tree in an area already well supplied with trees is probably not valued as highly as it would be in an area with few trees (other things being equal).
- Housing density – people in high-density areas likely have relatively low access to their own vegetated areas, meaning that they rely on public areas. In other words, they value an additional tree relatively highly because they lack access to substitutes.
- The need for specific benefits – flood mitigation is valued in areas where there is a flood risk, or heat mitigation where it is relatively hot.

For any type of benefit, including non-financial ones, willingness to pay tends to be higher for people who are relatively wealthy. Of course, this is also true for market goods.

There are a number of advantages in measuring environmental and social benefits in monetary terms.

- To allow comparisons of different types of environmental and social benefits. We need some sort of common currency to be able to compare benefits related to, say, recreation and water quality, and using money as this common currency is a natural and effective choice.
- To allow comparisons of environmental or social benefits with benefits from market transactions. Sometimes this is important to ensure that environmental and social benefits are given due weight by decision makers.
- To allow environmental and social benefits to be included in a Benefit: Cost Analysis (BCA) of a project or policy. A BCA allows us to judge whether the overall benefits of a project outweigh the overall costs. Without including monetised values for environmental and social benefits, some good projects may fail a Benefit: Cost Analysis test.
- To make a persuasive business case for investment in a project that generates environmental and social benefits.

Techniques for monetising values

Economists use a variety of techniques to estimate people's willingness to pay for urban trees and vegetation. The different techniques have different strengths and weaknesses. Here I will outline the three main methods that have been used for valuing trees.

"Hedonic Pricing" is often used to unpack the different values associated with land and property. Data for many property sales, with different characteristics, are collected. Some properties that are sold have positive environmental characteristics (e.g. they have a large tree on the front verge) while others don't. Statistical methods are used to tease out how much people actually pay for the environmental characteristics (e.g. Hamilton, 2005). This is only useful for a subset of environmental values – those that can be enjoyed as a result of buying land or property. The benefits measured are only for the landowners. If there are additional benefits for others, they would not be picked up by this technique.

The other two methods are based on surveys. "Contingent Valuation" is the most widely applied of these techniques (e.g. Epstein, 2003). There are various flavours of contingent valuation, but they all involve people responding to hypothetical questions about their willingness to pay for environmental benefits, or the compensation they would require in order to be willing to tolerate adverse environmental changes. For example, one version asks people whether they would be willing to pay at least $X for a particular environmental change. You vary X for different people, and ask lots of people the same questions, generating a distribution of values.

The other survey-based approach is called "Choice Experiments" (Hoyos Ramos, 2010; Gillespie and Kragt, 2012). It doesn't actually involve experiments in the physical sense, just hypothetical ones. People are offered sets of options and asked to choose the one they prefer. The options include various levels of environmental benefits, and usually include different costs of obtaining those benefits. If you design it well, and ask enough people, you can again use statistics to infer the dollar values that people assign to the environmental assets in question.

A weakness of the survey-based methods is that they rely on people responding to questions about hypothetical scenarios. If people really had to respond to those scenarios, they might behave differently from what they say in the survey. Research has shown that this does result in some "hypothetical bias", although in my judgement the size of this bias is not so large as to greatly reduce the benefits of using these techniques. Hedonic pricing is based on data from real purchasing decisions, so it does not suffer from hypothetical bias.

A strength of the survey-based approaches is that they can provide evidence about any type of benefit and for any group in the community. This sets them apart from hedonic pricing, which is limited to measuring the benefits that accrue to house owners as a result of them purchasing a property.

Evidence

A number of studies from around the world using the Hedonic Pricing method have shown that trees are valued by home owners. These include studies in Athens, Georgia (Anderson and Cordell (1988), Boton Rouge, Louisiana (Dombrow et al. 2000), Salo, Finland (Tyrvainene and Miettinen 2000) and eight towns or regions in the Netherlands (LuttiK 2000). In addition, there have been studies of the value of public open space that includes trees, including in Phoenix, Arizona (Abbott and Klaiber (2010). Within Australia, there have been studies by Pandit et al. (2013), Pandit et al. (2014), Tapsuwan et al. (2009), Polyakov et al. (2017) and a new unpublished study by Doll (2021a).

The specific results vary in different studies, reflecting different contexts, different locations and different research methods. The value of an individual tree can be surprisingly high. For example, Pandit et al. (2013) found that a mature broad-leaved tree (usually a eucalypt) on the street verge in Perth increased the median property sale price by $16,889, while a palm tree did not. The same eucalypt within the property boundary did not increase the house price.

In a similar study for a different region in Perth, Pandit et al. (2014) confirmed the high value of a mature street tree ($14,500). Interestingly, their analysis indicated that a tree can actually decrease the value of a house when it is located on the block or on the adjacent private property within 20 m of property boundary. The mean reduction was $6,100. They suggest several possible reasons for these reductions: blocking views, dropping leaves, damage to pavement, the increased risk of damage to property in a storm, and the occupation of valuable private space. The fact that the overall effect is negative means that these negative impacts outweigh the positive effects, such as amenity and shade.

The other three Australian Hedonic Pricing studies are also for Perth, but they are for public open space rather than individual trees. Tapsuwan et al. (2009) investigated the value of living close to public open space that includes a wetland, in the western suburbs of Perth. Although not a focus of the study, these areas also include many trees, and they would have contributed to the estimated value. They found that the existence of an area of public open space, including a wetland, within 1.5 km of a property will increase the average sales price by $6976. The aggregate effect on surrounding property prices could be very large, calculated as $140 million for one example.

Polyakov et al. (2017) estimated the value of converting a grassed paddock with a straight concrete drain into a natural area with dense vegetation (including many trees) and a meandering stream, in the Perth suburb of Lynwood. They found that homes within 200 m of the restoration site increased in value by 4.7% once the restored area became fully established, with a possible range of 2.9% to 6.5% (the confidence interval). With an average house price of $404,000, this equates to a benefit of $19,000 per house.

Finally, in this look at Hedonic Price studies, Doll (2021a) found that the value of living close to a park varied depending on housing density, park size, and the area of irrigated grass versus non-irrigated areas, including areas with native vegetation. As would be expected, the value was higher for people who live in high-density residences. For these people, all types of parks were valued; values were highest for small parks with irrigated grass, but were also high for the non-irrigated components of both small and large parks. Interestingly, for people in low- and medium-density housing, only the irrigated grass component of parks made a significant contribution to property values.

Doll (2021b) also did a Choice Experiment on the value of parks, looking more explicitly at the value of trees. Her analysis identified four groups of people in the population with broadly similar characteristics and preferences.

Group 1: younger, male, concerned about future water scarcity (36.83% of the sample)

- Holds high values for trees.
- Is somewhat indifferent between three land uses beneath the trees: watered grass, non-watered grass and native vegetation. Prefers all three of those to mulch.

Group 2: older, with kids at home, not concerned about future water scarcity (28.73%)

- Holds extremely high values for trees
- At the ground level, strongly prefers watered grass. Is indifferent between mulch, non-watered grass and native vegetation.

Group 3: not concerned about future water scarcity (20.55%)

- No significant preferences for or against any of the options.

Group 4: Older, concerned about future water scarcity (13.89%)

- Holds very high values for trees.
- Strongly dislikes, otherwise indifferent between mulch, non-watered grass and native vegetation.

The optimal design of parks includes a mixture of different element, and the preferred mix is somewhat different across the four groups.

Conclusion

Lessons from this research include the following. The techniques used provide rich insights into the values of trees. The value of a tree is highly context-specific. It can be very high, but it can also be negative. Different people have widely different preferences and values in relation to trees and vegetation. It means that diversity in the urban landscape is likely to be a good strategy.

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DEVELOPING AN AUSTRALIAN STREET TREE COST MODEL

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Abstract

The costs of maintaining an urban tree over its lifecycle have been considered in several models. However, are these models typical of larger urban street trees growing under Australian conditions? The costs of maintaining an urban street tree under Australian management regimes, including purchase and planting costs of a common street tree species, herbicide and mulching costs, the cost of irrigation over the first summer after spring planting and of formatively pruning the young tree were calculated based on data obtained from Australian local governments. The models demonstrated that costs associated with a street tree are high in the first 2-3 years of its life but much higher in the final year of life leading to removal. The lifetime costs of maintaining a street tree depending on the management scenario are between $2800 - $5300 and $56 - $106.00 per annum. Doubling the life span of a tree reduces the annual management cost by 30%.

Introduction

The costs of maintaining an urban tree over its lifecycle have been considered in a number of cost models, profiles or curves (Vogt et al. 2015). One often cited in an Australian municipal context is discussed by Hitchmough (1994), who provided a curve described as a typical relationship between the cost and functional and aesthetic benefits of the urban shrub mass (Figure 1). The maintenance cost of a tree is generally considered to be low when compared to other vegetation types (Hitchmough 1994; Vogt et al. 2015). While the curve provided by Hitchmough (1994) is a general model for the urban shrub mass, it is used for urban trees through an extension of the maturity phase to forty or more years. The Vogt et al. (2015) model also reflects higher costs in the establishment and decline phase.

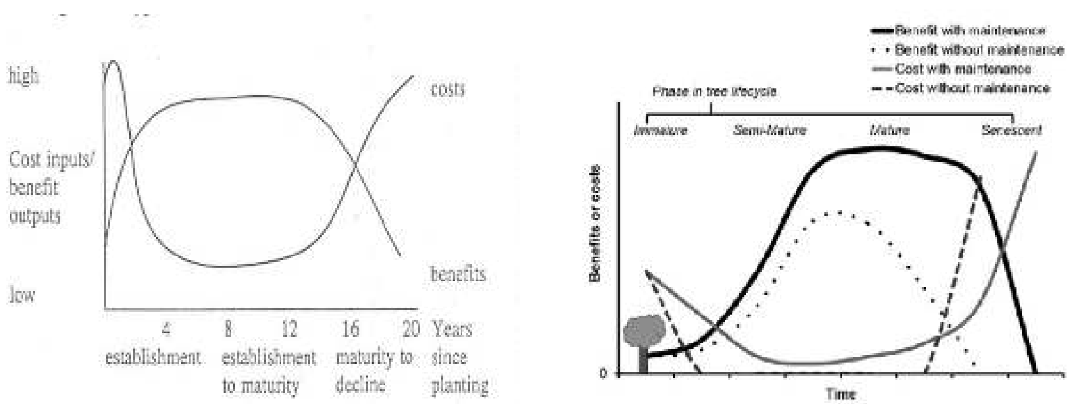

Figure 1. Relationships between maintenance costs and benefits and the life cycle of the urban shrub mass (from Hitchmough 1994, left) and a street tree (from Vogt et.al 2015, right).

The shapes of these curves are important as the impression that they give affects the way people make decisions about and manage trees. For example the curve of Hitchmough (1994) shows a small initial rise then a rapid fall and initial and final costs are similar, while Vogt et al. (2015) shows that initial costs are about 45% of those associated with final tree costs. However, do these curves accurately reflect the lifetime costs of larger, long-lived street tree growing under Australian conditions?

What is included in the costs associated with urban trees varies for different cities, but can include planting, pruning, pest management, irrigation, removal, administration, inspection, infrastructure repairs, litter cleaning and liability claims (Vargas et al. 2007; Fairman and Livesley 2011, Soares et al. 2011; Vogt et al. 2015).

Other costs of risk management, mulching, tree support and protection systems and soil management may not be included in estimates or budgets (Vogt 2015). However, the costs of planting, pruning, irrigation and removal tend to be among the higher costs for most cities (Hauer and Peterson 2016) with pest management and administrative costs being high in some cities and lower in others. The models of Vogt et al. (2015) provided curves with and without maintenance/management costs with a steady increase in costs as the tree senesces.

It is difficult to obtain data on street tree costs from Australian LGAs, because different entities account for and include different items in their costs which contrasts the situation in the USA where the 2014 Urban and Community Forestry Census of Tree Activities provided a revealing, in-depth snapshot of urban tree costs and management (Hauer and Peterson 2016). For LGAs ranging from large inner city to small rural councils, data extracted from their Annual Reports for populations ranging from 12-100 x10^3 trees, revealed that budget allocations per tree *per annum* ranged from $9.20 up to $39.99 with a typical allocation being between $10-12.00 but data were difficult to compare (Table 1). The narrowness of the range is surprising and may reflect that allocations to organisational units managing trees are made on the basis of an amount per tree (ie $10) rather than the actual financial needs for managing urban tree populations.

Table 1. Examples of tree maintenance expenditure on street and public park trees by three representative types of local government agencies (LGAs).

Local Government Agency	Locality	Year	Tree population	Expenditure ($)	Average per tree ($)	Source
State capital city	Inner city	2019	72000	800,000	11.11	Annual report
Major Regional city	Regional town	2015	100,000	1,000,000	10.00	Coroner report 2015
Small country shire	Rural shire	2017-8	12,500	115,000	9.20	Urban Street Trees Asset Management Plan

Many tree cost models recognise that after planting, street trees often receive very little regular maintenance if they are healthy and structurally sound (Hitchmough 1994; Vogt et al. 2015). However, in many parts of Australia, street trees are regularly pruned to maintain utility service clearances. Under the climatic conditions of Australia, utility line clearing may occur as frequently as every 3 years, or as occasionally as 7 years. Clearance pruning cycles are particularly important in parts of the continent where bushfires are a major concern but they are often similar to cycles in other parts of the world that experience a Mediterranean-type climate and to pruning cycles that are implemented for other reasons (Moore 2012; Anonymous 2013).

The life spans of urban trees, particularly street trees, tend to be shorter the closer they grow to the city centre when compared to the same species growing in inner parks and suburbs (Graves 1994; Moll and Urban 1989; Sæbø et al. 2003). While the goal is to have street trees that live for 50 to 100 years to maximise the benefits:cost ratio of the tree, only a small percentage of trees planted in urban and suburban USA each year survive more than 40 years (Moll and Urban 1989; Phillips 1993; Skeira and Moll 1994). While many trees (often 20-40%) die within the first 2-5 years post-planting, others die after about three decades, just when they reach a size that makes them valuable assets (Sampson 1989; Pauleit 2003; Bühler et al. 2007; Hilbert et al. 2019). However, longer lifespans are achievable and in Berlin the average life expectancy for an urban tree is 60 years (Pauleit 2003) and there are many examples of large old street trees in Australian cities that have survived for more than a century

While some mature trees are identified for removal after annual tree inspections followed by full tree risk assessments (Norris and Moore 2020), in many instances, mature, large, long-lived street trees are removed after some major arboricultural event such as storm damage, the failure of a codominant stem or the shedding of a major limb. These latter occurrences warrant a reactive, emergency response while the former may be scheduled as part of routine maintenance depending on the level and immediacy of the assessed risk.

Both involve a significant arboricultural intervention, but routine maintenance is more efficient and cost effective than reactive, emergency and service request responses, with the potential to reduce costs by 50% (Anonymous 2013).

Over the past two decades, there has been considerable research into the economic benefits provided by trees in the urban forest (McPherson 2003; Vargas et al. 2007; Nowak et al 2010; Sander et al. 2010; Soares et al. 2011; Song et al. 2018) and others have used various methods to put a monetary value on urban trees (Neilan 2005; Moore 2006; Price 2007; Helliwell 2008, Sarajevs 2011). Most of these studies do not consider the life time carbon costs associated with the production and planting of street trees or the high carbon footprint of the arboriculture industry (Petrie et al. 2016). The container nursery industry is a net greenhouse gas emitter (Kendall and McPherson, 2012) and it has been estimated that it may take 26-33 years of growth before a nursery produced specimen, such as red maple, *Acer rubrum*, achieves carbon neutrality and that after 60 years of growth, it would only sequester a net 800 kg CO_2e if production, planting, maintenance and removal were considered (Ingram 2012).

This brief paper considers some typical cost cycle scenarios that might be applied to a range of large, long-lived, urban, street trees commonly grown in Australian cities and major regional centres across Australia. The paper uses the real values of costs associated with planting, establishment and maintenance as the tree matures and the costs associated with the removal of the tree for a typical large, long-lived street tree in an Australian city. The data are presented in a form that looks at both annual and accumulated costs over a projected fifty-year life span of an urban tree. The data are then extended over a tree life span of 100 years, which is realistic for some urban street trees growing in Australian cities, to reveal what happens to costs if trees live longer.

METHOD

To compile a basis for calculating the costs of maintaining a typical urban street tree, the purchase and planting costs, the cost of irrigation over the first summer after spring planting and for formatively pruning the young tree were determined for a readily available street tree species planted into a typical urban/suburban street location. The costs were based on a sufficiently large number of plantings to ensure an economy of scale typical of a local municipality street tree planting program.

The cost of a mixed particle sized organic mulch was estimated at $10 per tree. Typically street trees were planted with 1.0m^2 of mulch around the trunk, usually to a depth of 100mm. Herbicide (Roundup - glyphosate 360g/L, Monsanto Australia) was applied at a cost of $10 per tree and formative pruning was undertaken according to the method of Ryder and Moore (2013) at a cost of $5 per tree, which allowed an average of between 2-3 secateurs or pole pruner cuts per tree. The cost of irrigation was calculated to be $10 per tree for a period of 17-18 weeks or $175. Under a typical irrigation regime trees would receive 40 L of water each week in a single application (Leers et al. 2017). Maintenance costs vary enormously but the cost of routine annual maintenance where applicable was estimated at $40 per tree *per annum*.

The cost of major tree surgery for a street tree after storm damage, the failure of a codominant stem or the shedding of a major limb requiring a two-person crew and taking two hours was calculated to be $500. The cost of utility line clearing was estimated at $200 per tree and the pruning cycle of clearing was five years. Finally, once a tree had senesced the cost of removal was determined to be $1600. This paper models the maintenance costs of an urban tree under different scenarios: each scenario based upon the planting of a tree 2-3.0m tall with a projected useful life expectancy of 50 years (Table 2).

S**cenario 1,** the tree is purchased, planted, mulched and irrigated over summer. The tree receives one visit for formative pruning. The total cost of planting the tree was calculated at $400. In its second year, the tree was again mulched, given herbicide treatment to eliminate weed competition and irrigated over its second summer with the cost being $200. In its third year, the tree receives eight weeks of irrigation over summer and a final; herbicide treatment and mulching at a cost of $100. Thereafter the tree receives only routine annual maintenance until, in its 43rd year, the tree has major arboriculture work after an event, such as storm damage, the failure of a codominant stem or the shedding of a major limb at a cost of $500. The tree is removed after 50 years at a cost of $1600.

Scenario 2 is identical to the first scenario, but without the provision for annual maintenance. This scenario would be typical of a majority of large, long-lived street trees growing in suburban Australia. **Scenario 3** is identical to the first scenario, but the tree is subjected to a regular 5-year cycle of maintenance after 15 years which may be for power line or other utility cable clearing. Because of the regular maintenance, there is no need for major arboriculture work (tree surgery) because the tree has been regularly pruned.

Finally, the impact of a longer lifespan where the tree survives for a century is presented using the costs associated with **Scenario 1**.

Table 2. Components of urban tree maintenance costs under three scenarios

Variable	Cost ($)	Scenario 1 Annual maint Arb event 43yr		Scenario 2 No maint Arb event 43yr		Scenario 3 Pruning 5yr No arb event	
		Freq	Cost ($)	Freq	Cost ($)	Freq	Cost ($)
Tree	**120**	1	120	1	120	1	120
Planting	**80**	1	80	1	80	1	80
Cost of Mulch	**10**	3	30	3	30	3	30
Formative Pruning	**5**	2	10	2	10	2	10
Herbicide application	**10**	3	30	3	30	3	30
Summer irrigation 1yr	**10**	17.5	175	17.5	175	17.5	175
Summer irrigation 2yr	**10**	17.5	175	17.5	175	17.5	175
Summer irrigation 3yr	**10**	8	80	8	80	8	80
Routine Maintenance	**40**	46	1840			40	1600
Utility pruning	**200**					7	1400
Major Tree Surgery	**500**	1	500	1	500		
Tree removal	**1600**	1	1600	1	1600	1	1600
TOTAL ($)			**4640**		**2800**		**5300**

RESULTS

Scenario 1 When the tree is purchased, planted, mulched, irrigated and formatively pruned over its first two summers, has one major arboricultural intervention and is removed after a 50-year life span the total cost (Figure 2) for maintaining the tree is: Total Lifespan Cost = $400+200+100+(46x40) +500+1600 = $4640.00. Under this scenario the average annual cost is $92.80 per annum.

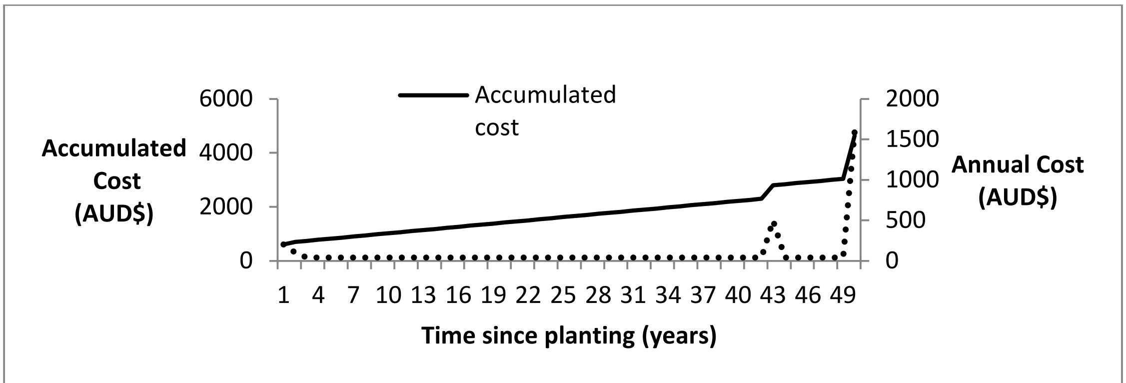

Figure 2. Annual and accumulated cost curves for Scenario 1 (Annual maintenance and a major arboricultural event in the 43rd year).

Scenario 2: With an identical scenario to the first but with no regular maintenance (Figure 3), the total cost for its 50-year life span is: Total Lifespan Cost = $400+200+100+500+1600 = $2800.00. Under this scenario the average annual cost is $56.00 per annum.

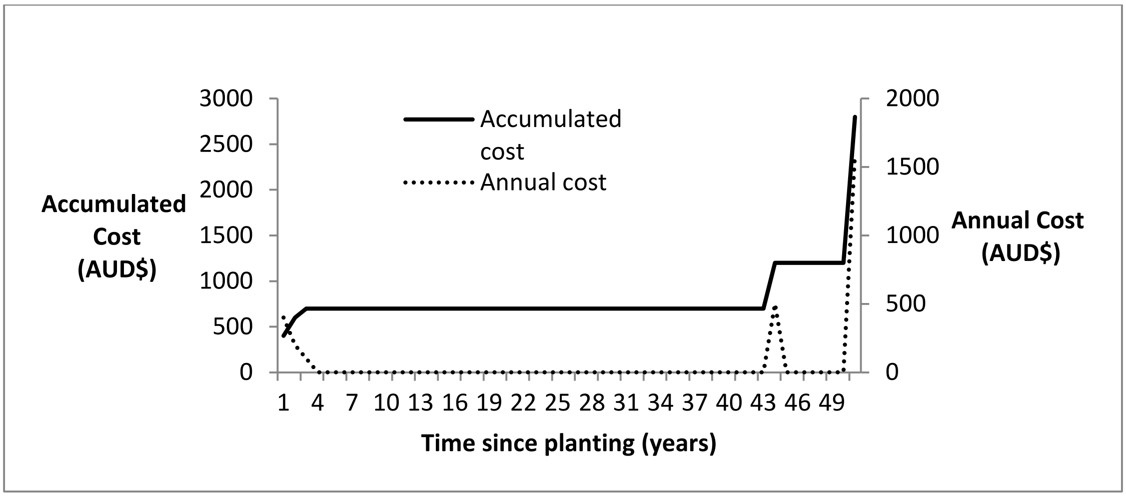

Figure 3. Annual and accumulated cost curves for scenario 2 (No annual maintenance and a major arboricultural event such as storm damage, failure of codominant stem or shedding of a major limb in the 43rd year).

Scenario 3: With an identical scenario to the first but with a regular 5 year cycle of maintenance after 15 years (Figure 4), the total cost for its 50 year life span is: Total Lifespan Cost = $400+200+100+(40x40)+(7x200)+1600 = $5300.00. Under this scenario the average annual cost is $106.00 per annum.

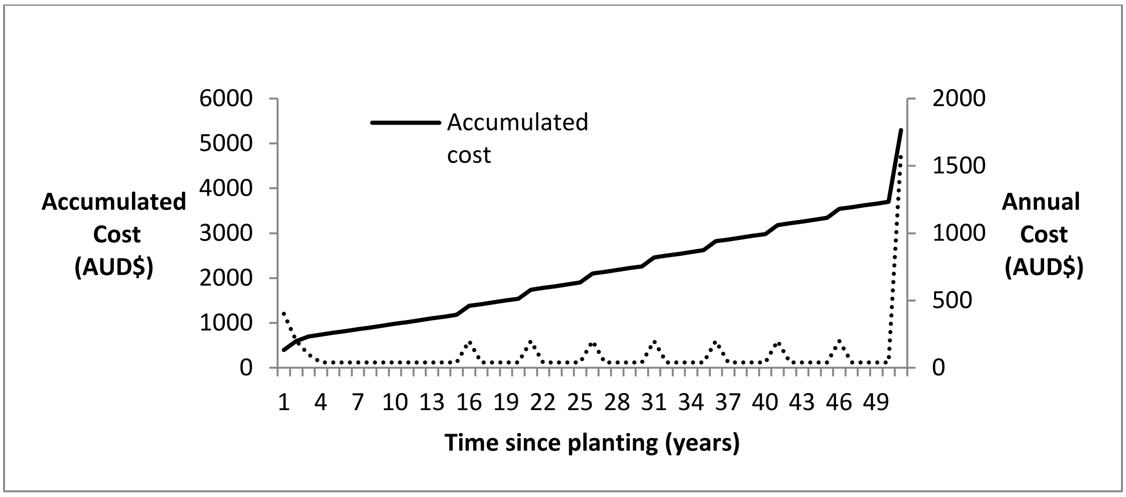

Figure 4. Annual and accumulated cost curves for scenario 3 (After 15 years, pruning every 5 years, but no major arboricultural event).

The results for an extended life span of a century for a tree under the cost structures of scenario 1 show that the total cost will be $6640 (Figure 5). The average annual cost for such a tree would be $66.40 which compares with the figure of $92.80 for a 50-year lifespan. The useful life span of a tree has a large impact on the cost associated with maintaining it, with a doubling of the life span reducing the annual average cost by 28.5%.

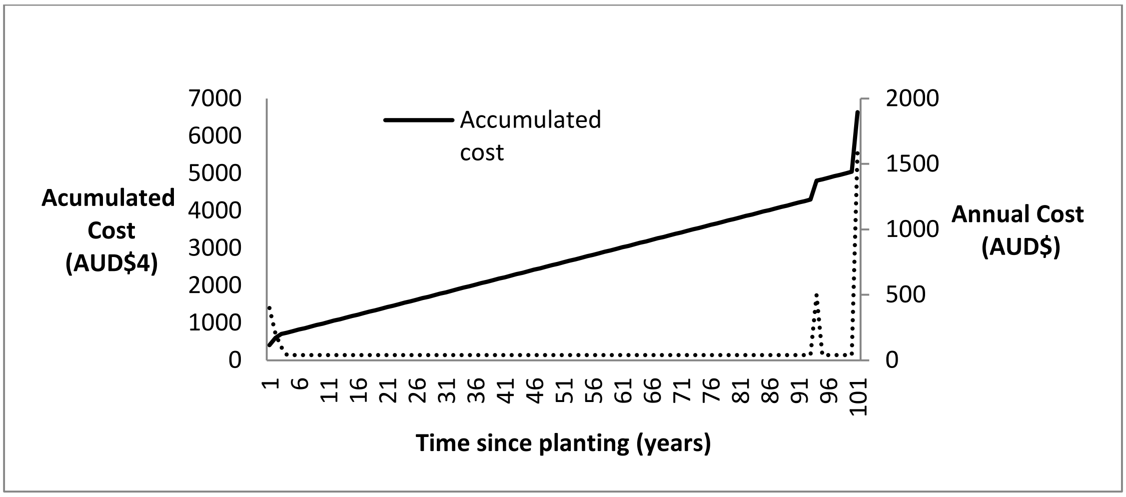

Figure 5. Annual and accumulated cost curves for scenario 1 for an extended life span of a century.

DISCUSSION

The curves demonstrate that costs associated with a typical street tree are highest in the first 2-3 years of its life and in the final year leading to removal, which is consistent with other tree costs models (Hitchmough 1994; Vogt et al. 2015). However, the shape and form of the curves are important as they convey implicit messages and the curves developed for this work differ significantly from other cost models in that the initial costs are much lower than the final costs (Figures 2-5). The costs are highest in the first year and then fall rapidly in the subsequent 2-3 years and then level off depending on the scenario. Other models (Figure 1) show the initial cost at 100% and 45% of the final year cost but the curves presented for these scenarios show that initial costs are only 25% of the costs of the final year. Costs fall rapidly after planting before rising more rapidly in the final year than other models predict. In the intervening period of 46 years for most of the scenarios proposed, the cost of maintaining the tree is very low. During this period, the costs associated with street trees are much lower and for much longer periods of time than other models demonstrate, which emphasizes just how low maintenance costs for an average street tree can be during this maturation and growth phase.

Looking at the accumulated cost curves, if the total costs of planting and maintaining a typical street tree are averaged over a fifty-year life span, the cost ranges from $92.80 to $124.40 per annum. Longer life spans have a significant effect on reducing the costs associated with urban street trees. A doubling of the lifespan of a tree under scenario 1 reduces annual coast by 28.5% and if there is no annual maintenance as in scenario 2, the costs are halved from $56.00 to $28.00 per annum, which highlights the economic value of maximizing the potential life spans of street trees.

If there is no annual routine maintenance, periodic utility line clearing and the tree does not shed any major limbs, annual costs may be very low for many decades and the only significant costs will be those associated with the final removal of the tree. Under the scenarios presented for street trees growing in Australia, the cost of final removal will be more-or less fixed as the removal of a single large street tree can be expensive. If a whole row or group of trees were removed at the same time, there will be economies of scale and the removal cost per tree could be significantly lowered. Planned routine maintenance is more efficient and cost effective, potentially reducing costs by as much as 50% by leveraging economies of scale from block pruning instead of emergency and service request responses (Anonymous 2013). There is an advantage in following planned tree replacement programs and letting removal contracts that attract such a discount.

The analyses of the curves indicate that the simplest ways of reducing the annual costs associated with a street tree are to eliminate regular high cost actions such as utility line clearing, eliminating the need for major arboricultural interventions and extending the tree's useful life. One way of eliminating the high cost of utility line clearing would be to underground services.

These services are very costly to retrofit, but one way of off-setting the expense could be by demonstrating the savings made in street tree maintenance, especially if useful life expectancy was extended due to reduced interference with the canopy (Andrews at al. 2010).

The retention of sequestered carbon in the street tree canopy with the elimination of line clearing and the increased environmental services such as shade, flood water mitigation and cooling would be added economic benefits (Moore 2009; 2016).

Eliminating the cost of the major arboricultural intervention, valued in these scenarios at $500, through preventative action such as formative pruning, which has been included in the costs of street tree establishment, could also significantly reduce costs. Formative pruning of young, and structural pruning of older street trees, not only reduce the likelihood of faults developing in the canopies but are economically efficient arboricultural practices (Ryder and Moore 2013). This would also reduce the risks of unplanned major arboricultural interventions requiring a reactive response which can be very expensive if work is done outside regular business hours or in high road traffic situations. Such an approach would also reduce the high carbon footprint currently associated with arboricultural intervention (Ingram 2012; Petrie et al. 2016).

Extending the useful life expectancies of urban street trees reduces their costs substantially for every decade of extra useful life. Ensuring that planted trees establish and survive the first 2-5 years post-planting would be a good start, as would avoiding the loss of trees that occurs at about three decades (Sampson 1989; Pauleit 2003; Bühler et al. 2007) so that more street trees survive beyond 40 years of age (Moll and Urban 1989; Phillips 1993). In a survey of over 300 mature urban southern conifers most of which were over 100 years old, Andrews et al (2010) concluded that freedom from urban development interfering with their roots systems and canopies was the most important factor contributing to their longevity and generally good health and vigour.

The costs presented under these different scenarios can be contrasted with the recent per annum benefit value calculations as part of a street tree benefit:cost analysis. In an Australian context, ecosystem service benefits of between $89 and $163.00 per annum were calculated using i-Tree (Fairman and Livesley 2011). While the total economic benefit (such as aesthetic, and real estate value) provided by a typical Adelaide street tree were estimated to be $424 per annum (Brindal and Stringer 2009). The cost scenarios provided in this paper allow more accurate benefit:cost ratios to be determined and the example of an Adelaide street tree would provide a benefit: cost ratio of between 3.4 and 4.6:1 for annual economic benefits versus total annual tree costs for the scenarios modelled. Urban street trees represent very good economic value to society and every effort must be made to maintain urban tree cover and prolong street tree longevity.

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PUTTING A DOLLAR VALUE ON URBAN FOREST BENEFITS

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Abstract

Many studies on the benefits of trees and urban green space have been completed in recent years, an increasing number of which calculate monetary value for what are currently non-market benefits. Published economic and financial benefits relate mainly to five services: amenity, shading, air quality, carbon sequestration and water management. Of these, amenity and shading provide the greatest economic benefit. Other benefits such as increased human productivity, reduced crime and enhanced biodiversity are increasingly being studied. Literature reports a massive increase in recent years in studies relating urban ecosystems to human health. Exposure to urban vegetation has been shown to be beneficial in terms of reducing the occurrence and seriousness of conditions including dementia, ADHD, and cardiometabolic disease, as well as being associated with healthier birth weights, better sleep, and increased physical exercise. Financial values have been calculated for these benefits. Other benefits, such as those related to childhood obesity, depression, and healthy gut microbiota, have not yet been quantified in economic terms. Other services such as those related to pollination, reduced wind velocity and amelioration of microplastics will also become better defined and quantified as further studies are done. Whilst these benefits and services are currently not paid for in the market, the consequences of loss of urban vegetation are being paid. Loss of urban vegetation results in increased stormwater discharge and related costs due to flooding, presentations for medical treatments for conditions which might otherwise have been prevented, and greater energy consumption and cost for home cooling and heating. This paper summarises the non-market benefits and services to which studies have either attached a dollar value, or to which a dollar value can be attributed.

Introduction

Studies on the benefits of urban green space have shown it moderates environmental impacts of urbanism and provides significant physical and mental health benefits. There are two types of benefits and services derived from trees – market (or commercial) and non-market. Market benefits include tradeable goods such as food and timber that can be harvested from orchards or commercial forest and marketable services such as entry fees for parks or reserves or carbon dioxide sequestration credits. Non-market benefits may have economic or financial value, but these values may be less tangible and are not currently traded in markets.

Some urban tree or ecosystem services can be neatly measured in financial terms. A reduction in storm water infrastructure costs may be based on volume of rainwater retained by trees or ecosystems, for example. Other services provided by urban trees or ecosystems are not easily measured in financial terms, if at all. Some of these services may be measured in relative ways, using a 'cost-effectiveness analysis', for example. Such analyses compare the results of two or more courses of action, where outcomes themselves can be counted and compared. Examples could be

- in regard to physical or mental health costs, a reduced number of presentations for treatment, reduced cost of prescribed medication, or a reduced number of disability-adjusted life years;
- for urban heat island or climate change mitigation strategies, the decrease in temperature;
- for human development benefits, added IQ points or cognitive gains for children.

Other techniques which can be used to attribute monetary values to non-market services are broadly categorised under 'stated' or 'revealed' valuation methods. Stated valuation methods rely on surveys in which people are asked about their preferences. The two main stated valuations methods are the contingent valuation method and choice experiments. The contingent valuation method uses a hypothetical scenario to find out how much people are willing to pay to improve an outcome given a range of alternate costed scenarios.

Revealed valuation methods look at what consumers actually do and the prices they pay, rather than what they say they might do. The 'hedonic method' is a revealed valuation technique which relates market sales of a commodity to non-market benefits. For example, property sales prices when compared with proximity to green space often show higher prices for houses closer to the green space. This non-market value is termed the 'amenity value'. The 'travel cost method' is another revealed valuation technique which is based on a comparison of the number of times a place is visited to the cost of visiting it. Methods to assess avoided costs such as foregone medical expenses if one maintains good health (or does not fall ill to a particular condition), or from averting undesirable behaviour, have also been heavily used in the literature regarding the impact of urban nature on human health.

Monetary value is among many values attributed to trees, and potentially of lesser importance than others. It is only one way of considering tree value and it may not be a suitable metric in some situations. Some attributes of trees may never be measurable financially, such as historical and cultural connections with Aboriginal shelter trees, canoe trees and others, and personal attachments to trees planted as memorials. Trees like the Tree of Knowledge in Barcaldine, Queensland, Melbourne's Separation Tree, the Glebe Grey ironbark and Moreton Bay Figs in Sydney; South Australia's Proclamation Tree, the Crowhurst Yew in Surrey, UK, Sir Isaac Newton's Apple Tree, and the offspring of the Liberty Tree in the United States and the Lone Pine in Australia. Many such trees may be considered beyond price by some. Different methodologies to represent these values may need to be developed.

Attaching a monetary value to benefits and services provided by urban trees will, however, assist their incorporation as 'green infrastructure' in engineering and urban design related decision processes, as government and business decisions are often based in economics. As urban trees can provide a net economic benefit, then they should be included in benefit/cost analyses.

The benefit of urban greenspace during local or global crises has recently been highlighted during COVID-19 lockdowns. Access to public and private green space has been linked to better health and wellbeing and has been found to be an essential health resource in times of crisis (Poortinga et al., 2021). Lu et al. (2021) reported that higher proportions of green space were correlated with lowered rate of infection with severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) across the USA. Lu et al. (2021) suggested that adequate provision of accessible and well-designed green space in urban areas, and preservation of natural green spaces across counties, should be incorporated into epidemic and pandemic resilience strategies for highly urbanized areas.

This paper summarises the results of reviews which identified benefits and services provided by urban trees at an individual tree level, species level, or broader urban forest (ecosystem) level. The focus of this paper was primarily on studies which attributed financial values to these services. The paper includes some project specific studies which related Australian data.

Method

As an initial investigation of the methods used to attribute monetary values to trees, this study sought to review the many papers published on the benefits of urban trees and vegetation in recent years. An initial literature search using keywords related to the economic value of urban trees in one database alone yielded 8,114 papers, the majority published since 2015. Given the scale of this literature, to capture the most relevant information this review focused on those papers which themselves were a review of other studies. The literature review was limited to papers published in the last 5 years; this included approximately 200 review papers. Abstracts of these review papers were first read to confirm their relevance to the topic. Peer reviewed academic papers specific to Australia and Australian technical reports, or papers considered to be of benefit due to their economic analyses, were selectively included. In this way, the resulting number of papers reviewed and summarised in this narrative was reduced to 60.

Literature Review

In a major seminal paper on the value of ecosystem services, the economic value delivered by natural systems across the global biosphere was assessed at US $33 trillion dollars annually (in 1994 values) (Costanza et al. 1997). Most of these services were non-market values. Since then, specific research on the economic value of a range of ecosystem services has been undertaken. The most recent reviews of monetary values associated with services provided by urban trees are summarised below. This is followed by further detail for specific services and benefits of trees and urban vegetation, apart from those specifically related to health. Health-related benefits are described in a separate section. Other benefits which have been highlighted by papers but have not yet had a monetary value placed on them are summarised at the end.

General reviews of non-market values

Song et al. (2018) systematically examined literature which jointly analysed both the costs and benefits of urban trees. Thirty-four original research papers published between 1992 and 2016 were reviewed and, where multiple studies reported values, their monetary values were reported as averages. Most of the studies were based in North America.

Monetary values reported related mainly to five services provided by urban trees: amenity, shading, air quality, carbon sequestration and storm water management. Overall Song et al. (2018) reported that the majority of the research focused on values which did not provide the greatest economic benefits of trees. They found aesthetic, amenity, and shading benefits of trees were less studied but of greater economic value than those related to air quality and carbon regulation. They noted that the studies available in the literature were 'snapshots' in time for the benefits and costs of urban trees, whereas trees are often long lived and can change over time. Of the 26 papers they reviewed which undertook a benefit cost analysis, 22 showed the benefits outweighed the costs. The mean benefit:cost ratio across all studies was 5.43, and the median 2.72.

In keeping with this finding, two South Australian studies (Smart Rd, Modbury and Felixstow wetlands, Felixstow), calculated urban vegetation-related monetary values in relation to health, water quality, stormwater run-off attenuation and amenity (termed 'neighbourhood character') (Martinez et al. 2019). The highest monetary benefit was calculated for amenity, based on '*willingness to pay for living in a greener neighbourhood',* by using residential property values as a surrogate measure. Using extensive evidence associating close proximity to green infrastructure with higher property values, they estimated a 4% increase in the value of those properties for each 10% increase in greening.

In another 'willingness to pay' review, Bockarjova et al. (2020) considered 60 primary studies on economic valuations of green and blue nature in cities worldwide. Suggesting that the willingness to pay method captured a wider variety of use and non-use values than revealed preference studies which only captured direct use values, Bockarjova et al. (2020) found green and blue space values for recreation, preservation, aesthetics, climate regulation, noise reduction, flood regulation and cultural services. Interestingly, the values related to Gross Domestic Product (GDP) per capita. GDP is generally higher in developing countries and often associated with higher urbanisation and reduced connection to nature, so these values are likely to increase with expected further growth in per capita GDP and continued urbanization globally.

Mangroves were found to 'provide many ecosystem services including provisioning (e.g. timber, fuel wood and charcoal), regulating (e.g. flood, storm and erosion control; prevention of salt water intrusion), habitat (e.g. breeding, spawning, and nursery habitat for commercial fish species, biodiversity), and cultural services (e.g. recreation, aesthetic, non-use)' (Brander et al. 2012). Monetary values attributed to these services are detailed in later sections.

Green space and natural urban areas such as wetlands, and other spaces that assist in the management of surface water, often overlap with values and benefits attributed to 'water sensitive urban design' (WSUD). WSUD aims to minimize negative influences of urban development on the hydrological cycle through green engineering to deliver economic, environmental and social benefits (Castonguay et al., 2018). A review of 194 studies from around the world which valued non-market benefits of water sensitive urban systems identified over 400 non-market values (Gunawardena et al. 2020). Of these non-market values attributed to WSUD, 30% related to green infrastructure values related mainly to urban amenity and recreational opportunities.

In recent years, studies of the human health benefits of urban trees and green space have added significantly to previously published values. Literature published up to the end of September 2019 was reviewed by Chen et al. (2020); it revealed correlations between urban nature and positive health effects on humans, but reported that few studies attributed financial values to these benefits. 4 peer reviewed journal papers, 1 book chapter and 5 reports from the US, UK and South Korea reported that very substantial financial savings could be made by using urban nature to improve human health or to prevent harm. Health-related values are described in a later section.

Values of specific benefits and services

Findings which attributed monetary values to specific benefits and services of urban trees and vegetation are presented in this section. Dollar values were converted to 2021 $AUD values except in some few cases where it was more appropriate to specify US dollar values. Averaged values and Australian research data are presented below; all attributed values that were identified are listed in Appendix 1.

Averaged monetary values of the most frequently studied benefits are given in Song et al. (2018) and presented in Figure 1. These benefits were incrementally added to a value based on the physical structure of a tree (nominally $3,500 in Figure 1). This base value would be calculated using methods such as the Burnley Method, Helliwell or Standard Tree Evaluation Method, or other such methods. The $3,500 base value presented in Figure 1 is considered highly conservative and representative of a relatively small tree.

The additional monetary values are based on 20 years of tree service life, as averages of values that would likely be lost should an established tree, with for example a nominal life of 60 years, be removed 20 years prematurely. Such values might be considered if a healthy tree is removed prematurely, as the loss would not be limited to the structural value of the tree but also to loss of benefits in the replacement tree's sapling stage until it matures, i.e. seedlings and saplings do not provide the same services as a 40-year-old tree. However, as trees reach 20 years of age, they will be contributing benefits including some with financial value. In Figure 1 a simplistic approach is taken, and it is assumed that around 20 years of financial services from an established tree will be lost if it is removed and replaced. As an example, if the amenity or shading benefit is $250 per tree per year on average, this would equate loss of benefit worth $5,000 ($250 x 20 years) per tree. A calculation of how many new trees it takes to offset the removal of a healthy mature specimen might be based more reliably on leaf area, as proposed in Nowak and Aevermann (2019), as this attribute dominates in determining structural and functional value of trees. However, no single attribute can yield an indication of all tree-related services so calculated values will likely remain conservative.

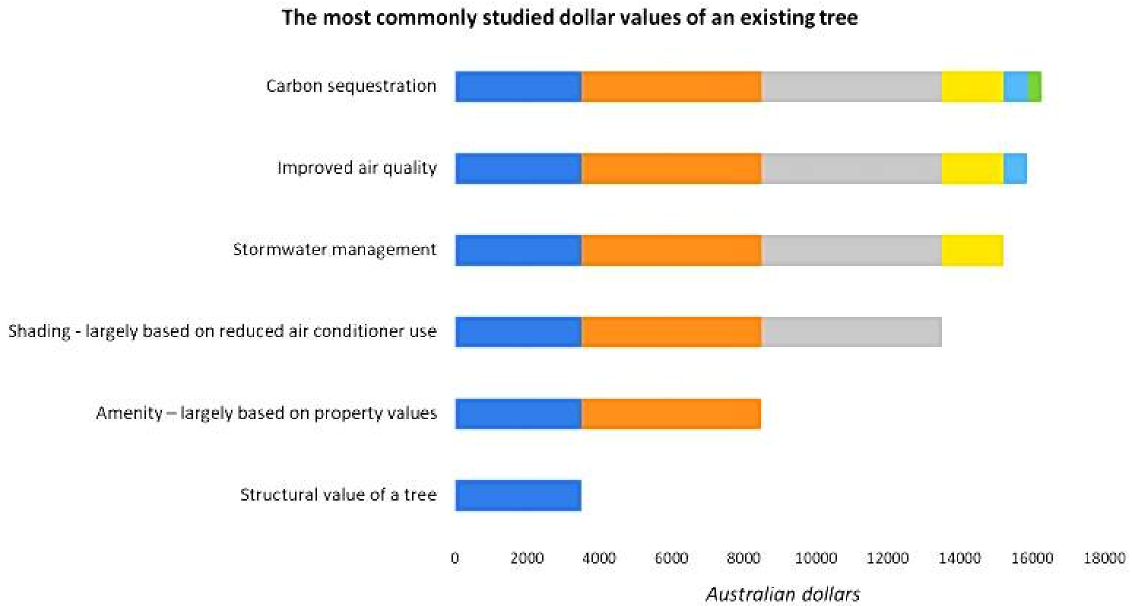

Figure 1. Averaged monetary values of the most studied benefits showing the monetary values that can be added to the structural base value of a tree (from Song, et al. 2018). The additional monetary value for every benefit is based on 20 years of tree services that would be lost should an established tree be replaced.

Aesthetic/amenity values

Amenity values for trees attributed using hedonic methods ranged between $13 and $270 per tree (Song et al. 2018). Pandit et al. (2013) reported that median property prices in Perth, Western Australia, increased by $23,290 due to broad leaved trees on street verges. Pandit et al. (2014) found that a 10% increase in tree canopy cover on adjacent public space increased properties by around 1.8% of the median property price. This equated to an increase of AUD $18,400 to the median property price (Gunawardena et al., 2020).

Analysis of 2,299 house sales across Brisbane, Queensland, found that houses with 50% or greater tree cover on the footpath within 100 m sold for 3.7% more than other houses (Plant et al. 2017). The price increase for a 1% increase in footpath tree cover within 100 m was between US $312–$393, or a premium of between 0.08–0.10% when evaluated at median house price. Flow-on effects in 2009-2010 to property tax revenues were estimated at $US 0.84–0.87 million in annual rates revenue to the council, and an estimated $US 0.87–0.98 million in stamp duty revenue to the state government.

Local values of green infrastructure stated in Martinez et al. (2019) for roadside greenery in five suburbs in South Australia were based on a 4% increase in property value for every 10% increase in greenspace. In 2019, the addition of trees, raingardens and wetlands along various stretches of road resulted in an overall calculated benefit from $28,277 (Florence St, City of Unley) to $ 4,426,523 (Felixstow wetlands, Felixstow) within the project's first 30 years.

Shading and temperature reduction

Song et al. (2018) reported that the benefit with the second highest economic value (second to amenity value) was due to reduced use of air conditioning in response to increased shading. Net energy savings of between 12 kWh and 919 kWh per tree per year were reported, supporting customer savings of between $6 and $270 per tree per year.

Nowak et al. (2017) indicated reduced energy use of residential buildings due to the shade, evapotranspiration cooling impact and wind velocity reduction of trees around buildings in the US. Overall, the US urban/community forest annually decreased energy use by 7.2%. This equated to savings to consumers of US$ 7.8 billion per year. Of this, savings of US$ 4.7 billion resulted from reduced electricity use for cooling and US$ 3.1 billion for heating. Shading also improves urban forest resilience, and protects asphalt roads and footpaths from heat-related degradation. Detailed investigation of these benefits is required.

Mitigation of the Urban Heat Island effects

Urban heat island effects are increasingly reported and quantified globally; urban areas become significantly warmer than surrounding rural regions during the day and radiate additional heat during the night. Studies have reported strong correlations between urban heat island effects, increased heat-related morbidity and other negative outcomes including impacts on human health, energy costs, thermal comfort, labour productivity, and antisocial behaviour (Yenneti et al. 2020). Urban heat island intensities (the temperature difference between urban and peri-urban areas) ranged between 1.0 °C to 13.0 °C (Yenneti et al. 2020), and for every degree rise in temperature above 18 °C energy consumption for cooling increased by 0.5% to 8.5%. The cooling energy demand of urban buildings was at least 13% higher than similar rural buildings. Urban overheating may also impact the Australian economy by reducing labour productivity (Yenneti et al., 2020).

Bayulken et al. (2020) included reviews of literature which showed urban heat can be reduced by 3◦ to 5◦ C across different cities and urban settings by increasing tree canopy. In Australia, Yenneti et al. (2020) found that urban greenery, especially trees and hedges, had high potential for urban heat island mitigation. The economic value of urban heat island mitigation was calculated for a precinct in Melbourne - a maximum greening scenario resulted in 2 degrees of cooling, which was valued at over AUD$1,500 per household over the 50 year study period (Newton and Rogers, 2020; Whiteoak and Saigar, 2019). Gunawardena et al. (2020) noted a lack of research on the economic value of urban heat island mitigation through greening.

Storm water management

Trees can intercept, absorb and adsorb rainfall on their leaves, branches, and bark, and stem-flow increases soakage into the soil beneath their canopies. This interception decreases the volume of water entering the drainage system during rainfall events. Infrastructure can also divert stormwater to provide passive irrigation for trees, which can result in savings for water management downstream (Nowak et al. 2018).

The scale and cost of stormwater management infrastructure can be reduced by using urban green spaces, trees and other vegetation. Bayulken et al. (2020) reported runoff from impermeable surfaces of between 50% and 90%, compared with runoff from vegetated areas of 13% (Elmqvist et al., 2015). Tree canopies can intercept between 4% and 50% of annual or seasonal rainfall depending on their canopy size, leaf area index, the local climate, and the intensity of urban heat island effects (Vilhar 2017). Song et al. (2018) reported stormwater mitigation costs could be reduced by between $0.45 and $88 per tree per year, based solely on rainfall interception by tree canopies. Stormwater management benefits of urban greening at the street scale in 5 different localities in South Australia were calculated to be up to $473,693 over 30 years (Martinez et al. 2019); the benefit due to attenuating of stormwater flows which reduced cost associated with flood damage.

Carbon sequestration

Carbon sequestration through biomass growth and storage, plus reduced carbon emission due reduced electricity usage for heating and cooling, has been reported as an economic benefit valued at between $0.50 to $22 per year per tree (Song et al. 2018). The value of carbon sequestration by urban forests in Canberra during 2008–2012 were reported in the range of $70–$236 per tree (Brack, 2002 in Gunawardena et al. 2017). Another Australian study investigated willingness to pay to implement climate change mitigation options and found residents in Canberra were willing to pay $191 per household per month to support a national emissions trading scheme (Akter and Bennett 2009). Salem and Mercer (2012) reviewed 73 studies of mangrove ecosystem service valuations and reported a mean financial value of $1560 per hectare per year for carbon sequestration.

Improved air quality

Trees can absorb and filter particulate matter, oxides and sulphides of nitrogen, and other pollutants to improve air quality (Samson et al. 2017). Estimated average economic benefits of improved air quality ranged from $1.00 to AUD $34 per tree per year (Song et al. 2018). The studies reviewed in Song et al. (2018) accounted for benefits in relation to ozone (O3), nitrogen dioxide (NO2), sulphur dioxide (SO2) and particulate matter less than 10 µm in size. Financial values of water and air purification by mangroves of $7,660 per hectare per year have been reported (Salem and Mercer, 2012).

Biodiversity

In summarising studies which reported values attributed to biodiversity, Gunawardena et al. (2017) noted general willingness to pay to protect biodiversity and ecology. A choice experiment conducted in Tasmania found people willing to pay $4.70, on average, to increase native vegetation along one kilometre of riverside and $10.00 per species to protect rare native plants and animals (Kragt and Bennett, 2011). Morrison and Bennett (2004) found people were willing to pay $11 per household for an additional fish species in rivers.

Plants have been the single greatest source of natural product drugs in recent decades. Three quarters of all anti-bacterial products approved by the USFDA between 1981 and 2010 can be traced back to natural product origins (Romanelli et al. 2015). The proportion of newly approved anti-virals and anti-parasitics was reported as similarly high, but to date only a small fraction of plant species have been studied to assess their pharmacologic potential.

Human productivity

Students who can view and observe nature during school have been shown to have higher standardized test scores, graduation rates and intent to pursue tertiary studies and reduced likelihood of involvement in future criminal behaviour (Chen, 2020). Improved performance at school can directly benefit individual students and society as a whole. The annual benefit in terms of increased average income, of the increased number of high school graduates due to the presence of urban nature whilst attending school, has been estimated at US$1.3 billion (Chen, 2020). The further economic benefit which would undoubtedly arise from additional spending due to this increased income has not been calculated. A study by Lee et al. (2017) reviewed in Gunawardena et al. (2017) noted observations that viewing nature during brief breaks helped restore and sustain employees' mental acuity throughout the workday, thus improving productivity.

Crime

Lower crime rates have been associated with greener neighbourhoods (Chen, 2020). Wolf et al. (2015) state Urban nature in US cities with populations over 500,000 potentially yielded savings of between US $340 and US $899 million due to reduced criminal activity during in 2012 (Wolf et al. 2015). The types of crime investigated included robbery, aggravated assault, burglary, and theft. The saving due to reduced aggravated assault alone ranged between US $340 and US $502 million in 2012 (Chen, 2020).

Coastal storm protection

Mangroves act to buffer coastlines and they significantly reduce damage during storm events. During cyclonic events mangroves significantly reduce water flow velocity (29–92%) and surge height (4–16.5 cm) (Dasgupta et al. 2019), potentially delivering significant savings from the avoided or reduced rehabilitation and maintenance expenses. Cyclone damage for villages in the 'mangrove shadow' has been shown to be approximately half that of villages not protected by mangroves (Akber et al. 2018); the value of this protection was calculated at $1676 per household (based on avoided damage repair expense). A meta-analysis reported in Salem and Mercer (2012) listed the mean financial value of coastal protection by mangroves as $5027 per hectare per year.

Tourism and recreation

A financial value has been attributed to recreation and tourism benefits in relation to mangroves of US $37,927 per hectare per year (in 2012 values) (Salem and Mercer 2012). No other literature was identified which specifically related tourism and recreation benefits in relation to urban trees.

General

A whole-of-life benefit–cost analysis was undertaken using the System of Environmental Economic Accounting (SEEA) framework, to estimate stocks and flows ecosystem services benefits of urban forests and irrigated open spaces in Canberra, Australia. The analysis used spatial data, i-Tree Eco, and benefit transfer methods for the period from 2018 to 2070. The analysis indicated that a 30% expansion of tree canopy cover yielded the highest benefit–cost ratio, while the business as usual scenario (loss of 400 trees expected per year) offered the lowest benefit–cost ratio (Tapsuwan et al. 2021).

A cost-benefit analysis relating to urban infill comparing no trees planted per allotment, one tree planted per allotment, or a tree funded to be planted off-site was undertaken for South Australia in 2020 (Econsearch, 2020). Using a very conservative number of benefits, it was found that the scenario involving planting a tree on every allotment would return $1.70 to the community for every $1 invested (a cost-benefit ratio of 1.7).

Monetised health values

The biophilia hypothesis suggests that human beings have an innate affinity withthe natural world and have evolved with a preference for the natural environments that are essential to wellbeing (Wilson, 1984). Recent studies have begun to quantify relationships between the natural world and human health, many of which have been investigated in terms of their monetary value. This affinity has economic implications; a review of 12 studies identified that urban citizens were willing to pay between $11 and $30 annually for not postponing or losing an outdoor experience and for walking in local environments (Lynch et al. 2020).

Mental health benefits

A survey reported in Dean et al. (2018), which involved 1,538 residents of Brisbane, Queensland, found that enjoyment of nature was consistently associated with reduced ill health. A marginal increase in visitation of public green space, of as little as once per week for thirty minutes per resident, was shown to be linked to a 7% reduction in the incidence of depression (Shanahan et al. 2016). With an estimated annual cost in Australia of $12.6 billion in 2010 (LaMontagne et al. 2010), or $16.9 billion in in 2021 dollar value, a 7% reduction would saving $1.2 billion.

Positive impacts of urban nature specifically on mental health have been documented in a review of twenty five papers by Callaghan et al. (2021). Mental health presentations in emergency departments have significantly increased since 2004, with over a quarter due to stress-related disorders (Tran et al., 2020). Depression accounts for 4.3% of the global burden of disease and is among the largest causes of disability worldwide, particularly for women (Romanelli et al., 2015).

Benefits worth between US $2.7 billion and US $6.8 billion could potentially be achieved across the United States from urban vegetation-related reductions in incidence and treatment costs in relation to ADHD, improved performance of high school students, crime reduction, reduced cardiovascular disease, reduced incidence of Alzheimer's disease, and health benefits accruing to newborns health benefits accruing to newborns (Wolf et al. 2015). The value of these benefits is likely to be conservative, as the estimates did not account for all of the known beneficial effects of urban nature (Chen 2020). Potential cost savings in Australia and globally due to the presence of urban nature are significant and should be further quantified.

Increased physical activity

Lack of physical activity increases risk of cardiovascular disease, diabetes, osteoarthritis, some forms of cancer, obesity and other diseases. Studies have shown decreased medical expenditure per physically active US citizen of between US $ 354 (in 2003 values) and US $ 564 (in 1998 values) (Chen 2020). Reduced health care costs and reduced morbidity due to increased physical activity were estimated to be valued at US $ 20 million in 2007 in Sacramento and US $ 69 million in Philadelphia.

For two sites in South Australia, Martinez et al. (2019) calculated avoided healthcare costs based on a 1% increase in the number of obese and overweight adults who participated in increased physical activity due to close proximity to green infrastructure. The researchers also calculated the likely monetary savings if 1% of insufficiently active adults increased their physical activity resulting in 2 additional life years per adult (the value of a statistical life year was estimated at AUD $187,000). They found the monetary value of health benefits amounted to $482,741. This conservative value considered only the adult population and a small proportion of the potential green space-related savings on health expenditure

Cardiometabolic diseases

Cardiometabolic diseases are the number one cause of death in the world (de Waard et al., 2018). Restoring local tree canopy in neighbourhoods may help to prevent these diseases. A study of 46,786 people aged over 45 years old found a 1% increase in tree canopy was associated with lower likelihood of diabetes, cardiovascular disease, incident diabetes and hypertension (Astell-Burt and Feng, 2020b).

Cardiovascular disease is a major component of public and private health care costs; between 25% and 30% of deaths in the US and UK respectively are caused by cardiovascular disease (Chen, 2020). Cardiovascular disease is more common in areas with reduced accessible green space, and a potential benefit worth US $1.43 billion (in 2021 values) has been reported as achievable through decreased cardiovascular treatments and morbidity in relation to males across the United States, if they have access to urban nature.

Air pollution

Air pollution causes adverse health conditions, with even brief exposure to particulate matter smaller than 2.5 µm (PM2.5) linked to increased hospital admissions for bronchitis, asthma, heart and lung problems, presentations for emergency medical treatments, and premature death. The potential transfer of micro-organisms and microbial species associated with particulate matter can increase human health problems. As an example, an analysis of severe smog events which caused rapid increases in patient presentations in hospitals in China due to respiratory issues revealed the existence of inhalable pathogens known to cause human respiratory diseases in air containing PM2.5 and PM10 particulates (Groulx et al., 2018).

Bayulken et al. (2020) reported 458,000 PM2.5-related deaths in urban populations across Europe in 2011. The European Union has set a limit on PM2.5 concentration of 25µg/m^3 (averaged over a year) since 2015. A meta-analysis of ambient air pollution revealed that exposure to both NO_2 and PM2.5 particulates increased the likelihood of pregnancy-induced hypertension and preeclampsia (Melody et al. 2020). A potential to reduce incidence of 49 cardiovascular diseases through pollutant removal by trees has been proposed, with annual saving in treatment costs of US $1.8 billion predicted (Nowak, 2014). The benefit resulting from removal of air pollution by trees across the USA has been reported as being worth US $4.7 billion in 2010 (Nowak et al. 2014).

Dementia

Dementia is the second highest cause of death in Australia. Recent studies indicate incidence of all-cause dementia and Alzheimer's type dementia are related to air pollution, and particularly to fine particulate matter. A study of over 30 years involving 4,000 residents in Seattle USA reported an increase of 1 mg of fine particle pollution per cubic metre of air near residences was associated with a 16% higher incidence of dementia (Shaffer et al., 2021). A similar response was reported in a French study, and a direct association between air pollution and increased beta amyloid production has now been identified (Alzheimers Association, 2021). Urban trees role in reducing air pollution and fine particulate matter may, therefore, play a role in reducing risk of dementia.

Dementia patients who used 'wander gardens' more than the median use had a significant reduction in high-dose antipsychotics (Chen, 2020). It has been estimated that wander gardens or 'horticultural therapy' might replace 5% to 10% of medication prescribed for Alzheimer patients, equivalent to reducing the cost of medication by between US $724.6 million and US $1.45 billion across the Unites States (Chen, 2020). A 'willingness to pay' study identified that therapy-related horticultural activity and sensory experiences in gardens in South Korea were values at US $170 per month per patient.

Studies conducted by CSIRO and NATSEM predict at least a doubling in the number of Australians with dementia over the next 30 years to between 900,000 and 1.1 million. Direct and indirect costs related to this disease are projected to increase in the range of 150% to 300%, to between $33 billion and $48 billion (Brown et al. 2017). Nearly 800,000 people would be needed as either paid or informal carers for dementia sufferers in the 2050s. The impact on future economic costs to the Australian community of only a small reduction in the incidence of Dementia by urban trees could be significant; a reduction of 2% would potentially save between $660 million and $980 million.

Attention deficit and hyperactivity disorder (ADHD)

Attention deficit hyperactivity disorder (ADHD) is an increasingly diagnosed brain disorder that is often treated with medication. In a US study it was found that a 20 minute walk in a city park was roughly equivalent to the 'peak effect of an extended release stimulant medication methylphenidate' (the most common ADHD medication) (Chen, 2020). Based on the extent of this effect and the cost of the drug, financial savings possible by treating ADHD through interaction with urban nature have been estimated to be between US $383.5 million to US $1.9 billion per year (corresponding to 5% and 25% medication replacement).

Birth weight

Birth weight is correlated with newborn, childhood and long-term health (Wolf et al., 2015). Newborns with low weight often require additional medical care as children, suffer more disease as adults, and are more likely to have lower IQ and lower income. Higher birth weight has been correlated with greater tree canopy in the USA, Spain, Germany and Canada, with estimated potential savings due to lower medical costs in the first year of a newborns life of US $ 6.3 million (in todays values) (Wolf et al. 2015).

Sleep

Lack of sleep is associated with increased risk of coronary heart disease, stroke, diabetes, obesity, depression, neurodegenerative diseases, inflammation, cardiovascular diseases, metabolic syndrome, injuries and premature death (Shin et al., 2020; Feng et al., 2020). In the US, insufficient sleep resulted in a financial loss of US $411 billion, or 2.28% of GDP in 2015 and such losses were predicted to increase (Shin et al. 2020). A systematic review of studies which investigated association between greenspace and sleep found that green space exposure improved both sleep quality and quantity (Shin et al. 2020).

An Australian study involving 38,982 citizens and which analysed sleep and proximity to green space found people living in or near locations with higher tree canopy cover were more likely to getting better sleep (Astell-Burt and Feng 2020a). Urban greening strategies which prioritise tree canopy cover may help to support population-wide improvements in sleep. An economic value specifically relating to green space and sleep was not identified in this review.

Non-monetised health values

Reviews of the benefits of green space which identified benefits which are likely to have economic benefit but which did not quantify the benefit in monetary terms are reported below to provide further perspective on the value of urban trees and vegetation and to potentially inspire future research.

Human health

Nieuwenhuijsen (2020) highlight Studies have reported non-monetised health benefits associated with greening cities including increased life expectancy, reduced frequency and severity of mental health incidents, improved cognitive functioning and mood, and improved infant health. A study which followed 108,630 women, recorded 8,604 deaths between 2000 and 2008, and which adjusted for other morbidity risk factors, found women living within 250 m of areas in areas categorised with the highest 20% of green space had a 12% lower rate of all-cause non-accidental death than those living in areas in the lowest20% of green space category (James et al. 2016). The associations were strongest in relation to respiratory and cancer-related deaths. A systematic review of 60 studies found higher levels of walkability and green spacewere associated with lower risk of type 2 diabetes, while increased levels of noise and air pollution were associated with greater risk (Dendup et al. 2018).

Significant beneficial effects of green and blue space on childhood obesity through influencing physical activity and eating behaviour have been reported (Alejandre and Lynch, 2020). Increased incidence of childhood obesity, higher electronic media use by younger children, reduced levels of outdoor activity and higher levels of emotional distress have been reported in older children living without green spaces nearby (Poulain et al., 2020).

The length of time spent in outdoor activity in winter by older children also increased with increasing access to green space (Poulain et al., 2020). Green and blue space may, therefore, have the potential to support policy, social, economic, environmental, and organisational initiatives to help to reduce childhood obesity and related health conditions.

Literature presents an established and increasing body of evidence for the positive relationship between mental well-being and accessibility to green space and nature. Urban green space can be established and sustained to support improved mental health of individuals and communities, particularly those of low socio-economic status, and vulnerable populations such as military Veterans (Barakat and Yousufzai, 2020). It has been suggested that future research shouldspecifically include the financial impact of urban vegetation on depression and obesity, with studies covering larger geographical areas to account for heterogeneities across countries (Chen 2020).

Pollinators

It has been suggested that green spaces including parks and urban gardens might asrefuges which help to preserve particularly vulnerable species of pollinator insects (Ayers and Rehan, 2021). Methods by which green spaces might be manipulated to promote greater pollinator abundance and diversity, increase native floral abundance and richness, and to reduce management intensity were suggested, including establishingareas of bare earth to support ground-nesting bees and increasing green infrastructure to reduce fragmentation and allowpollinator movement. A significant increase in the number of studies on pollinators in urban ecosystems has been observed in recent years, particularly in temperate region in developed nations including the United States, United Kingdom and France (Silva et al., 2020). No literature was identified in the review which reported economic value in relation urban forests on pollinators.

Biodiversity

Ecosystem integrity increases resilience to future events. Resilience within ecosystems, the capacity to buffer the effects of environmental impacts while retaining social and ecological function, has been de- scribed as the insurance value of an ecosystem (Green et al., 2016). Many biodiverse gardens dispersed across and throughout urban areas can help to insure cities against impacts like climate change, for example. Green et al. (2016) noted that any ecosystem's contribution to a benefit-cost analysis would be understated if ecosystem service values did not include a component for insurance (increased resilience), but that applying a monetary figure to theinsurance value of an ecosystem remained problematic. Although calling for better recognition of the insurance value of ecosystems, Green et al. (2016) advised against monetizing this property, as this might support the notion that loss of insurance value through ecosystem degradation could be compensated with financial capital.

Microplastics

Certain types of greenspace can capture pollutants from stormwater before it enters aquatic ecosystems. Microplastics have been highlighted as a ubiquitous problem in the natural environment (Geyer et al., 2017).

The amount of anthropogenic debris, including microplastics, in stormwaterrunoff was quantified in a study by Werbowski et al. (2021); it found debris was more concentrated in stormwater than in wastewater treatment plant effluent. Fibres and black rubbery fragments (potentially tire and road wear particles) made up 85% of all particles across all samples. Stormwater from theinlet and outlet of a 'rain garden' or 'bioretention system' (a low-lying area composed of native vegetation, engineered soil and organic matter) was analysed during 3 storm events to assess the mitigation capacity of the rain garden. The rain garden removed 96% of anthropogenic debris including 100% of black rubbery fragments (Werbowski et al, 2021). The researchers suggested that rain gardens should be explored more thoroughly to quantify their value as a mitigation strategy for microplastic pollution.

Reducing wind velocity

Tree and branch failures in severe wind events are routinely highlighted in mainstream media, but the protection from high velocity winds that is provided by trees is rarely if ever publicised even though the 'windbreak effect' is widely known in rural areas. Wind speeds are reduced on both the upwind and downwind sides of trees, although the effect is greater downwind. A study in Vancouver, Canada, reported that removing all trees in a neighbourhood could increase wind speeds by a factor of two (Giometto et al. 2017), and that removing all trees from around buildings increased their energy consumption by as much as 10 percent in the winter and 15 percent in the summer. Heating and cooling costs were reduced as lower wind speed resulted in reduced energy loss through draughts, and even bare trees can slow wind speeds (Giometto et al. 2017).

Reduced wind velocity creates more comfortable conditions for people spending time outside or walking along the street. Although wind has been considered in terms of costs associated with reduced air-conditioning use due to trees (see Nowak et al., 2017), the effectiveness and benefit of trees in reducing wind speed has not been adequately costed.

Emerging values

The value of urban trees is likely to increase in value in the future, as their mitigating effects on adverse human health conditions become more widely known. Illness and death due to urban heat island-related effects are predicted to increase. The recent death of a nine year old girl was attributed to nitrogen dioxide air pollution from traffic (Bikomeye et al., 2021). Increased urban tree cover can make a significant contribution toward ameliorating the negative impacts of these environmental factors (Osborne et al., 2021).

Urban biodiversity has been associated with differences in human-associated microbiota, and subsequent differences in immune function and mental outlook (Prescott et al. 2018). Modern medicine has been so successful against infectious disease, through development of antimicrobials, vaccines, and public health strategies, that non-communicable diseases have become the leading cause of mortality worldwide. Mills et al. (2020) reports that many non-communicable diseases arelinked to reduced diversity in environmental and human microbiota, and are increasing markedly in highly urbanised nations, so much so that biodiversity and ecosystem loss threaten to counter the major health improvements made over the last century (Queenan et al. 2017). The restoration and protection of urban green spaces with biologically diverse communities should be considered as a way to reduce the incidence of non-communicable diseases.

Conclusion

There is a large and growing body of literature which identifies and quantifies the various and often newly acknowledged benefits of urban trees and ecosystems across diverse functions such as urban heat island amelioration; climate change mitigation; storm water and microplastics management; biodiversity conservation; urban resilience; cultural, social and historical values; and physical and mental health improvement. However, on summarizing 2,194 papers on green infrastructure, Ying et al. (2021) reported that amongst the many studies which considered environmental and social aspects of green infrastructure, economic valuation studies were rare. Many benefits remain unquantified or under-quantified in the literature, but while some may be difficult to quantify, others are able to be reasonably reliably assessed in financial or economic terms.

Under-quantification of non-market benefits will undoubtedly limit their consideration by policy and decision makers, and sustain current difficulties in performing and understanding reliable benefit - cost analyses in relation to urban trees and urban ecosystems. Papers that applied monetary values to non-market benefits were largely presented research undertaken in North America. While local research has revealed some similar benefits, most have not yet been quantified in Australia. There is a need to quantify these benefits in an Australian context, so that locally specific tools may be progressed, underpinned by robust local data, to inform policy and project decision-making. Data are required over the extended periods throughout which benefits delivered by trees accrue, and for benefits which may currently be outside policy makers' areas of interest or regard.

Based on recent research and trends, the impact of quantifying non-market benefits on the monetary value of urban trees will be significant. For example, if projected annual costs of dementia in Australia of $48 billion are realised, a 1% reduction in air pollution resulting in a 1.6% reduction in dementia cases will deliver a saving in treatment and management costs of almost $770 million.

The rate at which studies are emerging, particularly in relation to personal benefits, health and the environment, suggest new direct and indirect benefits will continue to be identified and quantified. An important focus of future research should, therefore, be to develop methodologies and tools for agreed valuation metrics of benefits, that may not be financial or economic or may currently be poorly valued or aggregated, in order to inform certifiable comparisons across different projects, actions, opportunities or outcomes.

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Appendix 1. Table 1. Monetary values for urban tree services.

Value	Sub-value	Monetary valuations	Reference source	Notes
aesthetics and amenity	Hedonic - through property pricing	$7 to $165 per tree per year (US 2015 values)	Song et al (2018)	iTree or predecessor algorithms. Mostly from North America 1 year snapshot
	Hedonic - through property pricing	**Australia.** Property price increase from moving 1m closer to golf course, greenspace sport facility and coast was $0.54, $1.58 and $4.99 AUD respectively. Equates to US 2016 values of US$ 0.60, US$ 1.76 and US$ 5.56.	Mahmoudi et al. (2013) in Gunawardena et al (2017)	Looked at 40923 properties between years 2005 - 2008 in Adelaide metropolitan area
	Hedonic - through property pricing	**Australia.** Property price increase due to its postcode gaining green infrastructure equal to 1 standard deviation increase in enhanced vegetation index of US$ 34,195 to US$ 61,979 (in US 2016 values)	Rosseti (2013) in Gunawardena et al (2017)	Looked at 2,531,803 property transactions between years 2000- 2010 across Australia.
	Hedonic - through property pricing	**Australia.** A 10% increase in tree cover on adjacent public space resulted in a property price premium increase of about $14,500 AUD, equating to US 2016 values of US$ 13,188	Pandit et al (2014) in Gunawardena et al (2017)	Looked at 5606 properties in 2009 in central metropolitan Perth.
	Hedonic - through property pricing	**Australia**. Property price increase from increasing tree planting by 1% on footpaths within 100m of houses, was 0.082% to 1.03% of property price. 432.56	Plant et al. (2017) in Gunawardena et al (2017)	Studied 2774 houses in 2010 in Brisbane.
	Through 'experienced preference method' or 'life satisfaction approach'.	**Australia.** In 2016 values, an average implicit willingness to pay per household per year of US$ 940 for a 1% increase in public greenspace, and US$ 10,268 for 12.49% increase in public greenspace.	Ambrey and Fleming (2014) in Gunawardena et al (2017)	Studies all Australian capital cities, using Household Income and Labour Dynamics in Australia (HILDA) survey. (2005).
	Through contingency valuation and choice experiments	**Australia**. Annual willingness to pay per hectare of greenspace in 2003 was US $1,957 (2016 US values)	Brander and Koetse (2011) in Gunawardena et al (2017)	Based on 20 studies of urban or peri-urban open space across Australia, US, UK, Canada, China and Finland.
	Willingness to pay for preservation	**Australia**. Mean willingness to pay per person per annum for the local bushland in 2001 of US$ 14.79 (US 2016 values)	Pepper et al (2005) in Gunawardena et al (2017)	Results of over 500 questionnares in 2001 in Perth for preservation of bushland.
	Hedonic - through property pricing	Amsterdam. Homes 1 km or closer to green space sold at a price premium. The further the house from the green space, the lower the price premium. For example, they estimated a 7.1%–9.3% increase in price forhouses within 0.25 km from the nearest attractive green space to 1.7%–2.3% for houses located at 0.75–1.0km away	Daams et al (2019)	Using data on 35,298 home transactions in Amsterdam's urban core

	Hedonic - through property pricing	Leiden University in the Netherlands. Found on average people estimated house prices to be 5.05% and 6.07% greater for properties in a street with 25% and 50% tree cover respectively (compared to no tree cover)	Staats and Swain (2020)	surveyed 281 people
	Hedonic - through property pricing	Dalian in China. Found increased property values were estimated at AUD $1.6 million which equates to $34 per tree.	Wang et al (2018)	conducted a study of street trees using iTree in the main urban area
shading, evapotranspiration	Through reduced air-con use	$4 to $166 per tree per year (US 2015 values)	Song et al (2018)	
		US. Calculated reduced energy use of residential buildings **included impact of reduced wind** velocity and found urban/community forest annually decreased energy use by 7.2%. This equated to US$7.8 billion per year in energy costs. Of this, US$4.7 billion was from reduced electricity use and US$3.1 billion from reduced heating costs. Further to this, another US$ 357 per hectare year was saved from avoided emissions (equating to anadditional US$3.9 billion per year) derived from reduced emissions from power plants.	Nowak et al (2017)	
		New York City. Estimated that the 7 million trees in New York City, which create a canopy covering around 21% of the city, reduced annual residential energy costs by US$17.1 million per year in 2018.	Nowak et al (2018)	
		Dalian, China. Found avoided electricity and gas costs came to US$ 1.7 million, which on average equates to AUD$ 45/tree .Large-stature trees produced the greatest benefits - up to AUD$ 99 per tree.	Wang et al (2018)	iTree
air quality improvement	Through direct pollutant uptake and deposition.	-$0.68 to $21.28 per year per tree (US 2015 values)	Song et al (2018)	Used empirical mulitlayer and bigleaf models. Mostly from North America 1 year snapshot. To convert air quality benefits into monetary terms, most studies used shadow prices based on the cost of pollutant mitigation, while others estimated savings in healthcare.
	Savings to health care only	US$ 4.7 billion from pollution removal by urban forests and trees.	Nowak et al (2014) in Chen (2020)	

	PM2.5 reduction by trees	US$ 1.1 million to US$ 60.1 million. 12 different health incidences across 10 UScities, mostly from reducing mortality	Nowak et al (2013) in Chen (2020)	Investigated reduction of in-patient stays from potitive health impoact from reduced pollution due to urban trees. Other potential impacts such as direct and indirect exposure to nature and sensory stimuli from nature not investigated.
		Philadelphia. 15.7% canopy coverage annually removed 802 tons of air pollution valued at US$ 3.9 million	Nowak (2007) in Bayulken et al (2020)	
	Meta-analysis	Mangroves review. The mean financial values in regard to water and airpurification equate to AUD$ 7660 per hectare per year	Salem and Mercer (2012)	
		New York City. Estimated that the 7 million trees in New York City removes about 1,100 tons of airpollution per year which equates to a cost savings of US$ 78 million per year through avoided impacts on human health	Nowak et al (2018)	
		Dalian, China. Found the net benefits of air pollutant removal were valued at US $381,088/year or equivalent to AUD$ 10.19/tree	Wang et al (2018)	
	PM2.5 reduction by trees	US$ 1,876,000 in saved mediacl costs in US per year	Nowak et al (2014) in Chen (2020)	Estimated through saved medical costs in reduced cardiovscular hospital admissions.
carbon reduction	Through carbon sequestration of biomass	$0.34 to $13.38 per year per tree (US 2015 values)	Song et al (2018)	
		Canberra. Value of carbon sequestration by urban forests during 2008–2012 was estimated at $70–$236 per tree	Brack (2002)	
		Philadelphia. 15.7% canopy coverage provided carbon storage of 530,000 tons worth $9.8 million annually	Nowak (2007) in Bayulken et al (2020)	
	Meta-analysis	Mangrove ecosystems review. A mean financial value equivalent to AUD$ 1560per hectare per year for carbon sequestration.	Salem and Mercer (2012)	Undertook a meta-analysis on 73 studies (which totalled 352 observations) of mangrove ecosystem service valuations of either monetary or physical quantities
		New York City. Estimated that the 7 million trees in New York City removes about 51,000 tons of carbon per year (186,000 tons CO2/year), equating to a cost saving of US$ 6.8 million per year	Nowak et al (2018)	based on the economic impact of increased carbon emissions on factors such as agricultural productivity, human health, and property damages

		Dalian, China. Found the net annual CO2 removed by street trees totaled 36,111t, which equates to US $935,205. On a per tree basis, the carbon reduction benefits were on average equivalent to AUD$ 25	Wang et al (2018)	iTree
	Willingness to pay	Australia. Respondents in Canberra were willing to pay $191/household/month to support a national emissions trading scheme known as the Carbon Pollution Reduction Scheme	Akter and Bennett (2009)	
lowers crime		US$ 340.6 million to US$ 899.4 million from reduction in health care costs	Wolf et al (2015) in Chen (2020)	
stormwater management	Through canopy rainfall interception	$0.28 to $54.61 per tree per year	Song et al (2018)	Numerical model by Xiao et al (1998, 2000) which analysed reduced volume of water entering stormwater system through rainwater interception by canopies of individual trees.
		Portland Oregon. Project saved US $63 million by retaining and infiltrating storm water annually.	Bayulken et al (2020)	
		New York City. Estimated that the 7 million trees in New York City reduce runoff by 69 million cubicfeet/year which equates to a savings of $4.6 million/year through avoided surface water runoff.	Nowak et al (2018)	
		Dalian, China. A study of street trees in the main urban area found total stormwater runoff reduction benefits to Dalian were US $459,457, with an average value equivalent to AUD$ 12.35/tree		iTree
		South Australia. Cumulative benefit of greening a street in 5 different localities in South Australia would create a monetary benefit of AUD$ 473 693, to be reached within the project's first 30 years. This is due to water drainage attenuation reducing average annual flood damage costs.	Martinez et al (2019)	
coastal storm surge reduction		Bangladesh. Mean avoided damages from one cyclone (Sidr) for villages inmangrove shadow was US$ 938.4 (2007 values) per household.	Akbar et al (2018)	
horticlucture therapy		On average US$ 170/month per person willing to pay	Lee et al (2008) in Chen (2020)	

newborn birth weight		US$ 5.3 million savings (in 2012 value) for first year of all newborn baby's life in the US	Wolf et al (2015) in Chen (2020)	Reduction in medical costs due to correlation between tree canopy coverage of mother's home and increase in birth weight of singleton newborns. Monetary effects of later stages of their life has not been estimated.
promotes physical activity	**green assets promoting cycling**	£ 184.24 per extra cyclist due to reduced mortality (in UK?)	Green Infrastructure Northwest (2011) in Chen (2020)	
	green assets promoting cycling	NPV over 5 years is £ 0.6 million for cycling benefits in Erith Marshes and Belvedere	Green Infrastructure Northwest (2011) in Chen (2020)	
	green assets promoting walking	NPV over 5 years is £ 1.4 million for walking benefits Erith Marshes and Belvedere	Green Infrastructure Northwest (2011) in Chen (2020)	
	green assets promoting general physicality	US$ 1,98,71,863 in year 2007 in Sacramento	Chen (2020)	
	green assets promoting general physicality	US$ 1,94,19,000 in Philadelphia	Chen (2020)	
	A 1% reduction in the sedentary population	£ 1.44 billion per year in UK (equals a mean of £ 2,423 per additional active person a year)	CJC Consulting (2005) in Chen (2020)	
reduces cardiovascular disease		US$ 1.2 billion from reduced mortality costs	Wolf et al (2015) in Chen (2020)	Includes economic cost due to lost productivity, and correlation with populations living in greenest areas.
dementia/alzheimers		US$ 725 million to US$ 1.5 billion from reduced medical costs of Alzheimersdisease	Wolf et al (2015) in Chen (2020)	Wander gardens are outdoor confined spaces which permit unrestrained activities and prevent agitation in dementia patients. Wander have been shown to decrease falls and higher users require less medication. Costs are based on replacing between 5% and 10% of medication.
ADHD		Between US$ 383.5 million and US$ 1.9 billion	Wolf et al (2015) in Chen (2020)	Range relates to 5% and 25% possible medication replacement due to urban nature's effect of reducing ADHD symptoms.
increases school performance		US$ 1.3 billion per year	Wolf et al (2015) in Chen (2020)	In terms of increased income from higher secondary school performance due to urban natures effect on performance and capacity to direct attention. Does not include potential macro-economic effects.

sleep		US. A financial loss of $ 411 billion, or 2.28% of the GDP in 2015, was associatedwith insufficient sleep. These losses are projected to increase	Shin et al (2020)	Lack of sleep is associated with high risks of coronary heart disease, stroke, diabetes mellitus, obesity,depression, neurodegenerative diseases, inflammation, cardiovascular diseases, metabolic syndrome, injuriesand premature mortality (Shin et al., 2020; Feng et al., 2020)
tourism	meta-analysis	Mangrove review. Mean financial value of mangroves for recreation and tourism is US$ 37,927 per heactre per year (in 2012 values)	Salem and Mercer (2012)	
mental health		**Brisbane, Australia**. Results suggest that up to a further 7% of depression cases could be prevented if all city residents were to visit green spaces at least once a week for an average duration of 30 minutes or more. In 2007, estimated societal costs of depression were AUD$ 12.6 billion per annum for employed Australians alone (LaMontagne et al., 2010). This is equivalent to AUD$ 16.9 billion in 2021.	Shanahan et al (2016)	Used a population sample of 1538 residents of Brisbane City, Australia. It was found that a longer duration of individual nature experiences was significantly linked to a lower prevalence of depression. A higher frequency of green space visitation was also an important predictor for increased social cohesion.
gut biome health		no value found		
cognitive fatigue in		no value found		
general and child obesity		no value found		
pollination		no value found		
noise reduction		no value found		
recreation		no value found		
tourism		no value found		
wind reduction		no value found		
road maintenance		no value found		
humidifier		no value found		
biodiversity		no value found		

INVESTING IN TREES: IT'S A NO BRAINER!

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Abstract

The challenge for tree asset managers is to target timely investment to deliver the growth and longevity needed to ensure an appropriate return to the community. This is achievable with existing financial resources, but many young saplings currently fail in the landscape and so fail to deliver reasonable return on investment. By targeting investment to provide suitable root zone conditions, unnecessary cost imposts associated with remedial works and premature tree loss can be avoided. Investing in root zones not only enhances tree-related returns, but it can also support integration with other urban infrastructure to achieve synergies to reduce costs overall. The technical knowledge and expertise needed to guide wise investment in trees is not new, it is well developed and expanding. This expertise must be more widely applied to guide investment in tree assets throughout their planning, establishment, growth, maturity and senescence. Achieving this requires a transition from current practises toward broader collaboration of the professions responsible for installing trees. Only through collaboration can the necessary specialist inputs be applied during urban planning, design and construction processes and sustained into tree planting and maintenance by knowledgeable and skilled tradespeople. This paper introduces some historic and contemporary examples of wise investment in trees to focus thought on how good returns can be reliably achieved. It presents the need to invest in adequate soil quality and quantity in a controlled manner to sustain acceptable returns, and it shows that such investment is a 'NO BRAINER' which will grow community wealth.

Introduction

Public and private investors direct funds to plant and maintain trees in streets, parks and gardens across Australia and the world. Investing in trees involves paying. Trees on public land are community investments, paid for by rates or taxes. By investing in trees communities are investing in their health and wellbeing, in environmental management, climate moderation and adaptation, flood control, pollution management and many other necessities. Communities demand acceptable returns on the rates and taxes they pay and return on investment in trees can be massive so they pay professionals to manage these investments, but many trees fail to thrive and return on investment is absent. Regularly achieving good return on investment requires knowledge of the asset, its environment, its market i.e. community, and holistic understanding of how these interact.

Trees are appreciating assets which deliver benefits of substantial value

Trees are living assets which take time to mature, and timely investment and maintenance are essential for them to produce their best returns into the long term. Poorly targeted investment in trees often leads to ongoing spending to sustain poorly performing assets and to remove and replace trees prematurely. Loss and renewal of poor tree investments can become repetitive and expensive if causes of failure are not addressed. This can result not only in reduced returns, but it can also diminish the community's capital.

Urban trees have been '…acknowledged as both *productive capital stocks* and as components of *public infrastructural systems.* As ecological analogs of industrial capacity and physical infrastructure,…'(Killicoat, Puzio & Stringer 2002). Defining their value still proves unnecessarily difficult, however, as some in the community prefer that monetary values not be ascribed to trees and the aesthetic, environmental and other benefits they provide. In Australia, gaining widespread acceptance for a system to define values for amenity trees has proved chronically problematic. Several attempts to establish an Australian Standard all met with strong opposition and were abandoned. The draft Australian Standard on amenity tree valuation was '*…the longest unresolved or unfinalised standard with which Standards Australia has been associated… opposition of the powerful insurance and utility sectors virtually doomed it* ' (Moore 2006).

Valuing the services or benefits delivered by trees is challenging but research is increasing, as is monitoring of tree costs. Annual economic benefits exceeding $200 per tree and additional 'once-off' lifetime service values such as carbon sequestration and reduced deterioration of asphaltic pavements were calculated by Moore (2009). An earlier economic assessment of a small set of tree-related services delivered by a 'standard' Adelaide street tree (a 4.5 m tall Jacaranda) indicated an annual benefit worth $171 (Killicoat, Puzio & Stringer 2002), which was later revised to $424 per year (Brindal & Stringer 2009), or $540 CPI adjusted to 2021. These calculations of the economic value of tree-generated community benefits (or return on investment) are considered to be highly conservative.

The author's experience suggests the estimated annualised cost for a Jacaranda growing clear of utilities, in quality soil, in a street in suburban Adelaide, is $38 per year over a life cycle of 90 years. An annual return of $540 in value for tree-related services, therefore, represents an annual rate of return of 1400%. This figure greatly exceeds that reported by (Moore 2021), and neither include a component for the many health-related benefits of trees. Suburbs in Adelaide's inner south contain many Jacaranda street trees of 70 - 90 years of age which are in good health; their low annualised cost reflects their infrequent and typically small maintenance needs (provided they are protected from urban stresses e.g. root damage due to utilities and development impacts).

In considering the difficulties associated with managing trees as financial assets, Brindal and Stringer (2009) noted that '*Fixing an accurate value is one of the challenges we face*'. Variation in estimates of tree costs and benefits such as those described in the previous paragraph will likely be raised in the ongoing case against transitioning to economics-based decision making in regard to trees, perhaps even by some in the insurance, utility and development industries. The fact is, however, that the costs and benefits of all asset types vary. Consider the life-cycle costs of two identical vehicles, one that is driven and maintained well and another which is driven and maintained poorly. The costs and levels of service delivered by these two assets will be vastly different. Roads built on different soils and subject to different traffic loads and volumes wear at different rates, so their life-cycle costs vary markedly. Variability is an everyday reality in asset management. Variability does not make economics-based decisions more difficult in relation to trees than for other asset types. Failing to require that trees be managed as financial assets perpetuates poor investment of and accountability for public funds.

After estimating the gross value of a typical Adelaide street tree at $25,500, Brindal and Stringer (2009) advised how return on investment in trees can be increased. They wrote that '*Providing a suitable environment for root growth promotes longevity and increases the economic efficiency of trees*.' Providing a suitable environment for root growth to support newly-planted saplings through to their old age is fundamental to achieving a good return on investment in trees. Many examples over the last two decades demonstrate that achieving this is possible while accommodating other essential urban infrastructure and urban land uses. Where soil volume or quality is inadequate or uncertain, wise investment must begin below ground before the trees are planted. Without appropriate investment to investigate and ensure the adequacy of soil at the planting site, tree failures will continue and communities will be robbed of their due returns.

The fundamental needs of trees are well understood; they have been widely published. Most of a tree's water and nutrient needs are supplied from below ground; water is extracted from the soil and transported initially through roots. Low-strength, highly porous soils which support infiltration of water and diffusion of gasses support root growth and function (Smith, May & Moore 2001; Watson et al. 2014a, 2014b). As well as providing for trees, some urban soils must provide mechanical support for pavements and other engineered structures. Strong, high-density soils typically specified to support engineered structures do not support vital root growth and function (Day & Bassuk 1994; Watson & Kelsey 2006).

A sufficient volume of quality soil is needed to establish and sustain urban trees (Kopinga 1991; Leake & Haege 2016; Sanders & Grabosky 2014), to enable their roots to access sufficient water through the seasons (Clark & Kjelgren 1990; Lindsey & Bassuk 1992; Vico, Revelli & Porporato 2014). Competition for space in cities, between trees, utilities and other infrastructure, adds to the complexity of provision of sufficiently large soil volumes for trees (Meyer-McLean et al. 2021).

In addition to these requirements of competing infrastructure, the fact that tree size and water requirements vary in different climates, seasons, soil types and locations makes the need for timely expert input into design and planning processes very clear. The complexities of these interactions increase the costs of built and natural infrastructure components alike. If the services and benefits delivered by trees are undervalued then decision makers may consider these costs to be too high, but, if appropriate values are recognised, then informed decisions can be made to best serve local communities. Decisions based on fuller understanding of the economics of trees would likely increase the planting of large avenues into the future.

What value would we put on an avenue?

The avenue of London plane (*Platanus* x *hispanica*) in Frome Road in Adelaide was planted on Arbor Day in 1902 (Oldrey 2003). It is a South Australian icon. The trees are average examples of the species, they are not exceptional in any way. Some of the original trees have been replaced; some have been removed and not replaced. The avenue is listed in the National Trust of South Australia's Register of Significant Trees. The avenue is significant and it is held in trust, but what is it worth?

Towards the end of last millennium the health of some trees in the avenue began to suffer. Gas leakage was detected - a common occurrence in streets with ageing infrastructure. Recognizing the importance of the avenue, the asset's owners decommissioned the pipe to stop the leakage. They delivered gas to their customers using other pipes. The avenue was worth turning off the leaky pipe for.

Figure 1. London plane (*Platanus* x *hispanica*), Frome Road, Adelaide, South Australia, 5 April 2021.

Frome Road's plane tree avenue is approximately 500 m long. In addition to over 15,500 cars each day the road services two university campuses and what was, until recently, the Royal Adelaide Hospital. The capacities of the utilities which service these major institutions exceed those needed by many country towns. Much of the infrastructure which supplies these needs is located in the root zones of Frome Road's plane trees.

In the early 1980s one of the utilities companies needed to renew its pipes. Recognizing the importance of the avenue, the asset's owners employed labourers to manually excavate trenches to install the new pipes. The job progressed over many weeks and digging proceeded around the roots with minimal injury to them. Pipe sections were manually handled into place through the roots and laid in the base of the trench beneath them. Service connections into adjoining properties were similarly laid with manual labour. The labour cost would have been high, but the asset's managers (or perhaps their regulators) must have believed that the avenue justified the expense.

Frome Road's utilities and street assets have been installed and some have been renewed since the avenue was planted. We do not know how much extra the additional design, labour, and maintenance costs due to the trees have amounted to during the avenue's life to date, but it is clear that the avenue has been considered well worth the extra costs. Frome Road's avenue is appreciated and valued by the community.

The community would hold to account anyone who would devalue or diminish it. Investment in Frome Road's avenue was and is a 'no brainer'.

Looking after the avenue by continuing to invest in it, and requiring other asset managers to not harm or diminish it, is a no brainer because its benefit and value are obvious to the local community. This is so because the avenue is highly visible, or rather because it's above ground parts are highly visible. The avenue is valued because the community enjoys the benefits it provides, because the community invested in it over a century ago. Would the community be prepared to invest as much if the avenue did not yet exist? Would the community be prepared to invest as much to plant a new avenue of this scale elsewhere? Clearly, it is worth it. Planting new avenues is a no brainer, provided that they establish and thrive.

The installation of utilities and the construction of road, drainage, and footpath and bicycle infrastructure around Frome Road's trees is now history. The trees have undoubtedly increased the cost of these other assets. The community has paid these costs through rates, taxes and utilities bills. Asset owners do not pay these extra costs, their customers do. Utilities customers also pay for and benefit from the trees. With the benefit of hindsight, could there have been a better and cheaper way for the community to sustain the avenue and these other assets? Many successful investments in trees show that there is; many are detailed in the case studies portal on TREENET's Website (see: https://treenet.org/case_studies/).

Investing successfully in trees

Adelaide Street, Brisbane, Queensland

Nearly one hundred years after the Plane trees were planted in Adelaide's Frome Road, a local government-led program sought to revitalise precincts in Brisbane by creating pedestrian-friendly avenues. Concept plans for a project in Adelaide Street identified a suitable large tree species, but preliminary investigations revealed serious inadequacies in the root zones. Investing below ground to provide the conditions necessary for project success became a priority, and two traffic lanes were converted from car parking to create shared-use zones for pedestrians and tree roots (Plant 2002). Structural soils were used in continuous tree trenches beneath the parking and pedestrian areas. Twenty one trees were planted in this avenue, they all established rapidly and all have thrived to this day. The ongoing health of the avenue and quality of the streetscape attest to the value of this investment (Figure 2). In creating the tree root zones free of utilities the likelihood of root-infrastructure conflict and associated expenditure is greatly reduced, the health and longevity of the trees are enhanced, and return on investment is maximised. For further detail see: https://treenet.org/case_studies/adelaide-street-boulevard-brisbane-1999/

Figure 2. Leopard Tree (*Caesalpinia ferrea*) in Adelaide Street, Brisbane, planted 1999, (image: L. Plant)

Victoria Avenue, Chatswood, New South Wales

A paper presented at TREENET's annual symposium in 2011 demonstrated how good investment in trees was possible even when conditions at the planting site were extremely hostile to root growth. Victoria Avenue in the suburb of Chatswood in New South Wales had been converted from a main road to a pedestrian mall in 1989, but its deteriorating amenity led to its upgrading in 2009/10 (Smart 2011). Trees planted during the initial mall construction had performed poorly, and excavation revealed lack of suitable soil as the cause. In place of soil were heavily compacted rubble and high-strength concrete footings which had supported railway sleepers along the former tram track route (Figure 3).

The redundant transport engineering was replaced with quality soil, and load bearing pillars were built to support a pavement suspended above it (Figure 3). A bespoke stormwater infiltration system designed to also increase soil aeration between rain events further enhanced the tree root environment beneath the mall. The mall pavement was designed to accommodate service vehicles without compacting the soil or compromising tree growth. Further detail is available in Smart (2011).

Figure 3. Concrete and compacted rubble materials were removed from the Chatswood site (left) prior to installing quality soil blends in contiguous tree trenches (right)(Images: Arterra, R Smart)

Although the trees are still young, in their first decade they have developed sufficient canopy to provide shade to pedestrians and support commercial activity at the site (Figure 4). Incorporating stormwater harvesting into the design has delivered microclimate moderation benefits and reduced drainage needs downstream. The trees' health and size suggest this wise investment will continue to provide a good return well into the future.

Figure 4. Excellent tree health and vigour a decade after planting indicate return on investment has begun and is set to increase into the future (Image: Arterra, R Smart)

Bank Street, Adelaide, South Australia

Bank Street is a well-used pedestrian shortcut between the Adelaide Railway Station and many of the major commercial and civic precincts of the central business district. It is a narrow street which must also accommodate service vehicles and cars. Street furniture, vehicles and pedestrians didn't leave much room for trees (Figure 5). Adelaide City Council set about improving pedestrian access and amenity as part of a major upgrade of the street in 2017. Trees were to be planted for shade, but the site's soil was not suitable for root growth and utilities restricted available space.

Figure 5. Bank Street, Adelaide, prior to tree planting (Image: City of Adelaide)

Providing Bank Street's new trees with the soil volume necessary to sustain them into old age required investment. Funds were invested to create 'tree vaults' with structural cells to prevent soil compaction by traffic loads on the pavements used at the surface (Figure 6). After four years of growth the health and vigour of Bank Street's new saplings is apparent (Figure 7). The separation of tree roots and utilities in this manner will prevent or reduce costs due to tree injury or infrastructure damage. The scale of the species when mature will fill the streets without conflicting with nearby buildings, so reduction pruning will not be required and maintenance pruning will be minimal. Further detail on the Bank Street upgrade is available at: https://treenet.org/case_studies/bank-street-redevelopment/. The TREENET website contains many additional case studies which demonstrate successful strategies for establishing trees in highly developed and engineered situations.

Figure 6. Structural cells were used to support pavements in tree root zones in Bank Street, Adelaide. (image: City of Adelaide)

Figure 7. After four years Bank Street's saplings are already creating visual impact.

Successful investment in trees and associated assets

The 'per tree' cost reported in the case study notes for the Bank Street project was $35,000 (in 2017). This figure represented the total cost of the project divided by the number of trees. It included all the built assets, the pavement, drainage, artwork, signs and street furniture in addition to the tree-related components. The trees, soil and soil containment system was relatively inexpensive in comparison to these other items (Pope, S. 2021, pers com.).

In relation to the Adelaide Street case study, Plant (2002) estimated the cost of the tree-related components at 5% of the $35m budget (in 1999). In summing up the project a few years after construction she wrote:

> *'On a per tree basis, tree trench installation is much more costly than conventional street tree planting in a paved footpath. However, when costs of poor tree performance, higher maintenance of both tree and pavement, tree replacement and loss of amenity values are considered, there is little doubt that tree trench installations provide a cost effective alternative. Such installations are often a very small part of overall costs for large scale construction projects. In locations like car parks, where only slight changes are made to the existing construction processes, installation of alternative, tree root friendly pavement subgrades adds little cost.'*

The Victoria Avenue mall project's budget of $3.16 million (in 2009/10)(Smart 2011), met the cost of the total project including the civil engineering components and street furniture. This budget was not excessive for a major infrastructure upgrade of this nature and profile, yet it was sufficient to ameliorate the degraded site and allow the trees' soil requirements to be integrated into the overall infrastructure design. Site degradation is common on brownfield sites and it typically constrains projects, increases their cost, and contributes to poor tree performance. Degradation frequently results from abandonment of redundant assets, like the buried tram track sleepers and concrete footings in the Victoria Avenue case study, or dumping of toxic spoil such as concrete slurry or demolition rubble as 'clean fill' in areas which are to be landscaped.

As with the Bank Street and Adelaide Street examples, the Victoria Avenue project's smart design will avoid the conflicts and associated costs which typically arise when trees establish near infrastructure which isn't engineered to accommodate them.

Separation of tree roots and built infrastructure supports long term success, as does separation of tree roots from inappropriate fill, abandoned infrastructure and other waste materials. In most brownfield projects, specifications must include not only what is wanted, but they must also detail what is not permitted in tree root zones.

Although each of these recent case study projects was unique, the approach used to achieve success was similar. In these case studies the arboricultural knowledge needed to ensure the chosen tree species could thrive to old age was accessed initially during the concept design stage, and the project arborists remained involved throughout the process to completion. In each case the required tree root zone volume was achieved. Although the need to ensure the required soil quality and volume was common to the projects, the site's conditions, tree species, climate and environment made each project unique. Detailed specifications unique to each project were essential.

Although they were at the high end of the spectrum in terms of tree-related planting costs, these projects will deliver savings in the long term. In relation to the Victoria Avenue mall, Smart (2011) stated that the design intent was to create a legacy such that the trees would out-last the project's built components. By providing the tree root zone with quality soil free of utilities, Smart (2011) anticipated that future streetscape upgrades could readily proceed around the mature, healthy trees without impacting them. Given the longevity of the species and typical frequency of streetscape renewal in high-use precincts, it is likely that several cycles of streetscape renewal will proceed without losing the benefits delivered by the mature trees and without accruing future costs for tree renewal. These future savings will more than offset the marginally higher initial construction cost.

These capital city examples demonstrate that trees can be cost-effectively established and provisioned to deliver long, serviceable life cycles even in the harshest of urban environments. Most urban trees do not need structural soils, tree vaults or structural cells, so their costs will be lower. To reliably achieve results like those demonstrated by these capital city case studies communities need better investment in trees, not more investment.

Investing in trees and avenues for the future

As shown in the capital cities case studies, while it is the above ground parts of trees that are valued by communities, investment must be targeted below ground. In the Adelaide Street case study, the scale of the selected tree species led to the determination that the volume and quality of existing soil was inadequate, so soil provision became a priority. Similarly at Bank Street, the project aimed to install the largest volume of quality soil possible within the site's infrastructure constraints and then a tree species was selected which could grow to maturity in it. At Victoria Avenue a reasonable root volume existed but it contained engineered fill and rail base material, so the design focussed on optimising the continuity of tree trenches and selecting species which would thrive in them when refilled with appropriate soil.

The desirable return on investment provided by leafy tree canopies in these examples in highly developed urban environments cannot be achieved without investing in real estate for tree root zones (Figure 8). Achieving this relies on a series of interconnected events which in large development projects can progress over several years. Like interconnected links in a chain, if one of these essential components is weak or missing then the entire chain is compromised or fails.

The initial link in the chain of events (Figure 9) is genuine engagement, including the community and all related professions, to investigate and understand what is required so the concept can be reliably defined and specified. The next link includes concept design, then re-engagement prior to commencing detailed design and costing involving the client, professions and approvals agencies. It is important that each stage of decision making regarding planning, design and documentation is regarded as a necessarily collaborative link in the process that influences the outcome. The product of these early stages is tender documentation including specifications on what will be constructed and how it will be delivered.

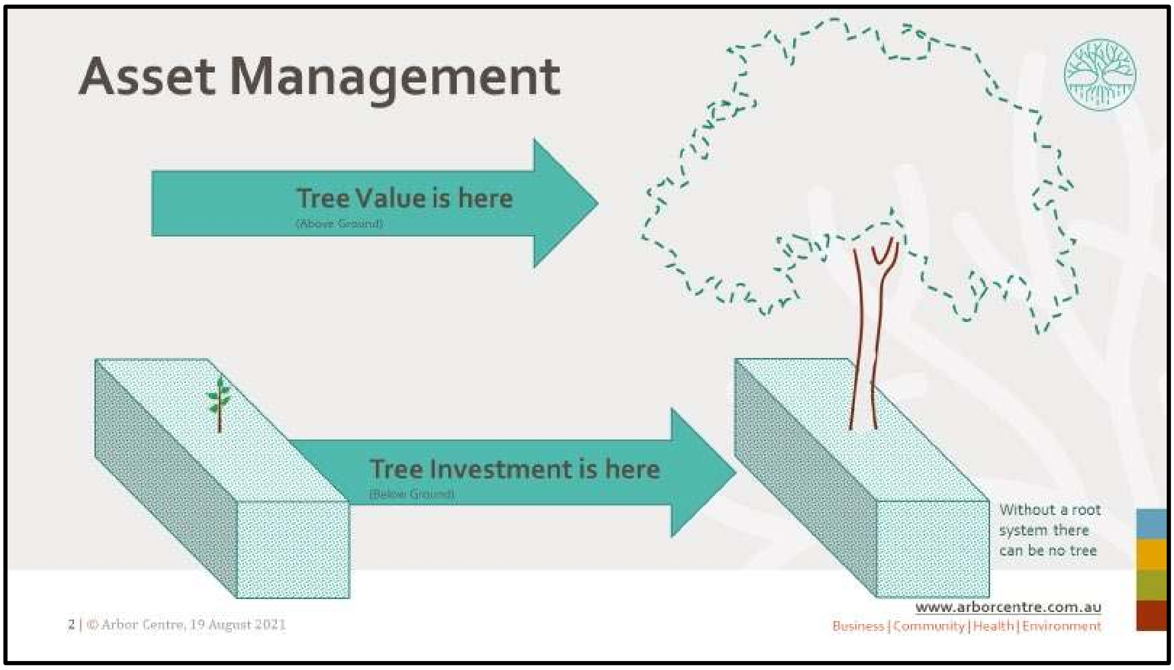

Figure 8. Investment below ground sustains benefits delivered by trees above ground

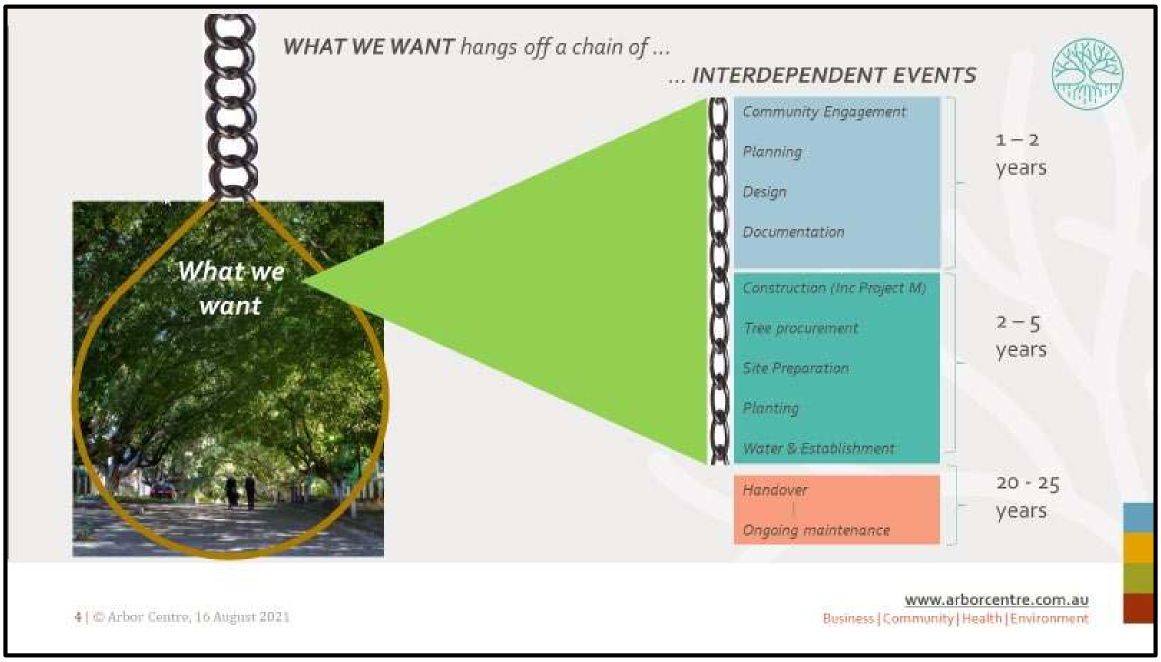

Figure 9. The interdependent chain of events that underpin a successful tree outcome.

The failure of new tree plantings associated with major and minor developments mostly occur within a few years of planting and commonly result from a primary focus being on the contract rather than on the outcome. This is not a failure of the individuals involved; it represents a failure of current systems. Project delivery typically becomes contractually fragmented in a financial attempt to minimise and control costs within every link of the chain of events. The focus at each stage being on cost rather than outcome (process-driven rather than outcome driven), frequently results in a failure to recognise the unique combination of site-specific variables that underpin successful tree establishment. Further, at the end of the contract period there is typically no effective 'fit for purpose' check that can be fairly applied to confirm tree establishment, little or no accountability for poor tree performance, and limited capacity to address poor tree performance.

Project participants including planners, urban designers, landscape architects, finance officers, and others from associated professions may be unaware of the influence that their decisions will have on trees into the long term. This seems largely because current systems do not keep them informed about, or accountable for, outcomes. The failure of trees to establish and thrive can result from many causes beyond the contractual obligations, so ongoing accountability is not readily achieved, and tree replacement on three, five and to ten year cycles is not uncommon, particularly in harsh, highly developed and or, disturbed environments. The cumulative cost of replacement plantings is significant and requires funding that has not been budgeted for in project costings.

To avoid poor investment of public funds, it is recommended that the post planting 'establishment phase' becomes part of the capital cost of a project. Budgets must be allocated over the 3 to 5 years needed to ensure that the tree is fit for purpose (without needing replacement) and the value of the benefits it provides begins to increase (Figure 10), rather than short-term (typically annual) budgeting in response to tree failure.

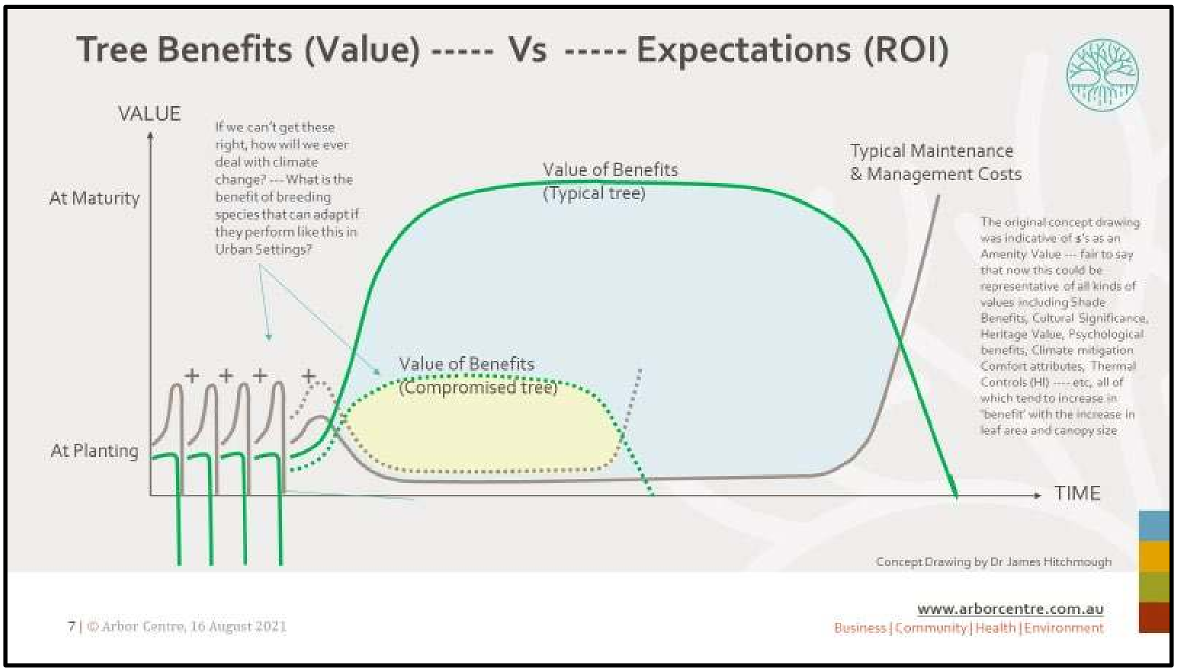

Figure 10. Survival rates and tree performance in situ, strongly influence the value of the benefits that a 'typical tree' can provide (the blue area showing the room for improvement).

Tree audits performed and decades of observations made by Arbor Centre, of many thousands of trees in Western Australian housing estates, municipal streets and roadside plantings, have indicative survival rates of less than 50% for tube stock plantings in the landscape within 2 years of planting. For larger container stock, survival rates within 3-5years of planting commonly range between 30% and 70%, and typically reduce to an overall survival rate ranging from 30% to 50 % after ten years (consensus of Local Govt Tree Managers and Supervisors at the 202020 Vision workshop – 2015). These low success ratios also apply to replacement trees, so planting costs can be more than double that of the original project estimate. Another common observation is that the growth of specimens that do establish is commonly compromised or suppressed. A low percentage of original plantings develop to the scale presented in preliminary concept drawings, planning application documentation and promotional material.

Size matters (Figure 11). The extent of benefits delivered by trees is typically proportional to canopy cover; the larger the canopy cover the larger the benefits. A typical healthy, mature Tuart (*Eucalyptus gomphocephala*) growing in Perth, Western Australia, has a canopy cover area comparable to four or five Western Australian Peppermints (*Agonis flexuosa*), so return on investment will be greater for the Tuart. Considering tree performance relative to size, and tree survival rates, brings the reality of investing in real estate for trees below ground into focus.

Real estate has value whether it is commercial or residential private property or allocated to utilities or tree roots in the public 'commons' which is the street. The soil volume needed to sustain a tree has value and cost. Without access to adequate root volume, benefits from trees will always be poor. Investing in trees costs relatively little in comparison with other street assets yet it delivers an enduring legacy – the underground real estate which can sustain successive generations of trees.

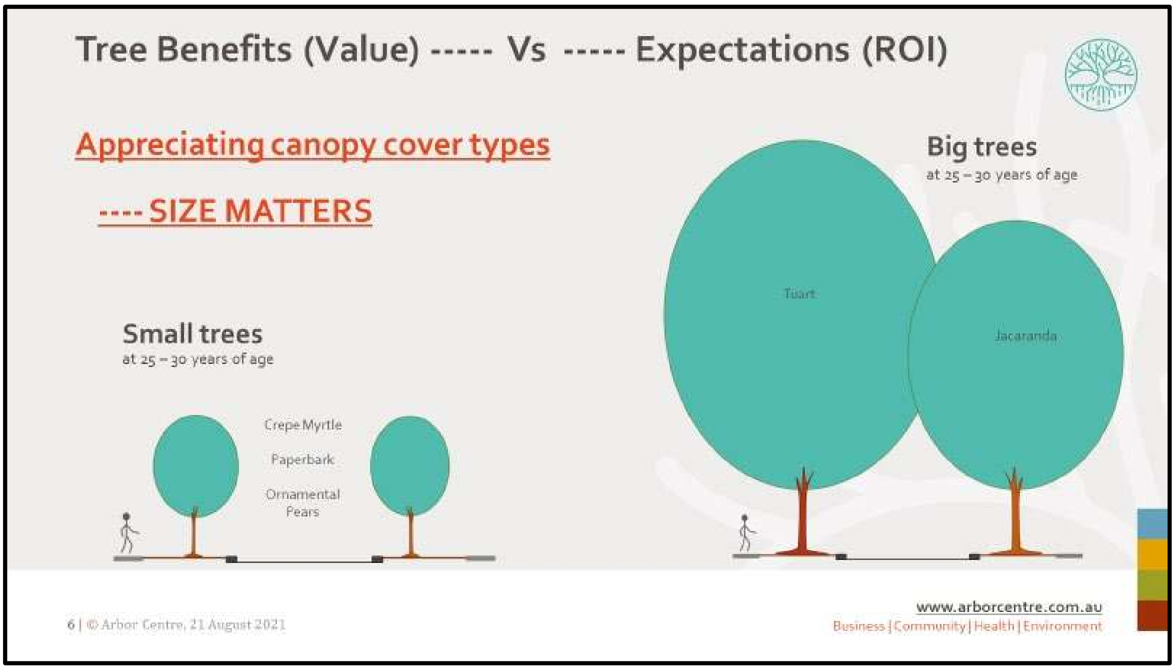

Figure 11. It takes the planting of numerous small tree species to provide the equivalent canopy cover of one large tree species. Large tree species also need more space for roots to grow to reach their potential.

Investment in trees requires provision of materials and practices that are easily quantified and budgeted for, including adequate soil volume, suitable soil and surface treatments, and designs and measures to protect built assets from tree roots and *vice versa*. If applied correctly, Australian Standard AS 4970 *Protection of trees on development sites* can assist the design of protection for all assets in proximity to an existing tree - the built assets and the tree! Aspects of the Australian Standard can also be applied to guide the design of spaces for new tree plantings. Investing in trees to enhance the above ground environment is well advanced, delivering on this investment requires investment below ground.

Conclusion

Improving urban tree performance by providing their fundamental water and nutrient requirements through the soil, and thus supporting their growth to maturity and old age, will increase return on investment (Figure 12). Investing in quality soil volume and separation from utilities and other built infrastructure does not require new money, but rather the repurposing and re-timing of resources which are typically made available within existing budgets. Recognising this is essential to increasing return on community investment in trees. Funding successful tree establishment and eliminating expenditure on maintaining and replacing poorly performing trees will increase return on community investment in trees. Designing tree planting sites to simultaneously prevent built infrastructure damage and tree root injury will increase community return on investment in trees.

Valuing and investing in construction below ground to sustain urban trees is making provision for generations of trees. This visionary approach has been demonstrated by the case studies presented in this paper and by many others, yet it still remains relatively novel. Widespread application of this approach will improve urban canopy and related benefits and result in long-term financial benefit to communities.

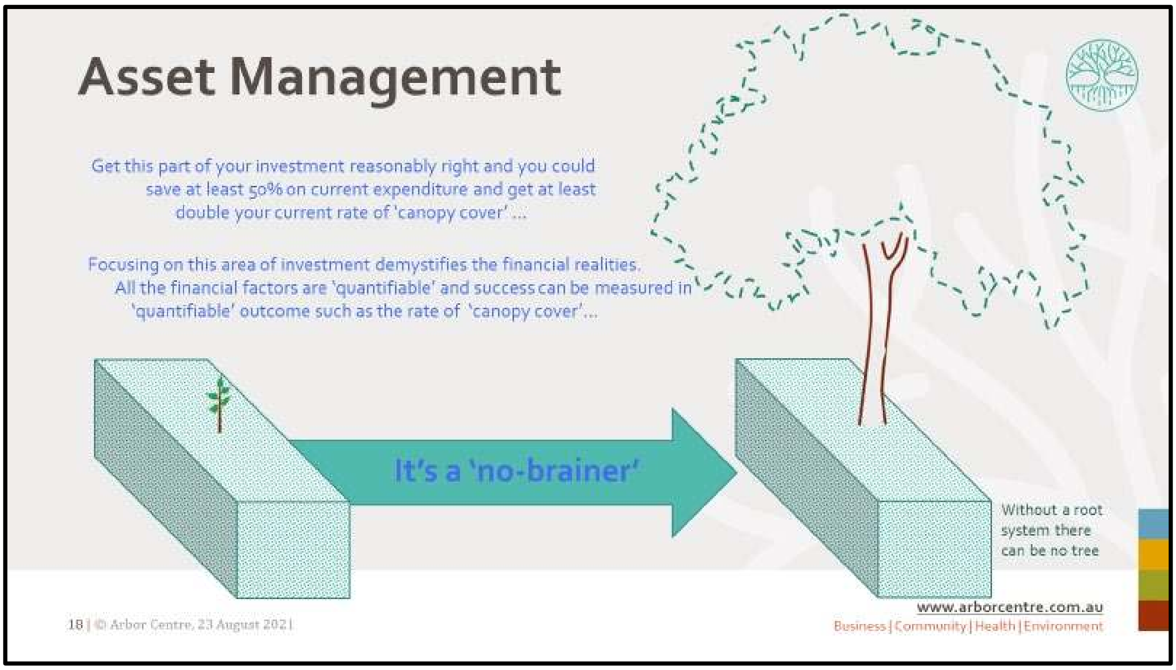

Figure 12. The return on investment from allocating a portion of the Public Realm real estate for trees for the purpose of managing where roots grow and to provide canopy cover, is a 'No-Brainer'

Transitioning communities and industry toward effective urban forestry through targeted investment below ground will be a piecewise process with each new project which establishes below-ground real estate for trees for future generations. Progress toward this goal will be supported by effective allocation and regulation of real estate in the public commons which is the street. Built infrastructure takes up a lot of space in the commons, often to the exclusion of all else. Returning nature generally, and trees in particular, to cities is known to be fundamental to human health and wellbeing, and this requires space.

Policy guidance and regulatory controls which enable space for urban natural capital, and for trees in particular, are needed as part of this transition. Understanding of the value of urban trees is increasing, but lack of accepted economic valuations for the services they deliver hampers effective decision making regarding allocation of space in the street commons. Reallocating space in the street commons to best serve communities requires that current allocations, such as separations between utilities as specified in historically adopted standards, be reviewed. Large separation from utilities takes up a lot of space in the street commons; they reduce management costs for utilities owners but fail to consider the much more substantial value of community benefits lost due to poor tree canopy coverage.

New or additional money is not needed to deliver effective urban forests, current allocations are generally sufficient although too frequently they are poorly targeted and timed. As part of major capital urban development projects, the cost to establish trees effectively is small, returns are great, and returns can be enduring. While tree costs can be recorded with precision, the values of the many services they provide need to be reliably quantified to balance decision making in relation to investment in trees. Regulatory support for allocation of space for trees, as utilities and other built infrastructure is installed or renewed, will increase opportunities for communities to invest wisely in their urban forests. Communities deserve opportunities to invest wisely in their street commons in ways which guarantee successful urban tree provision, avoid damage to structures and utilities, eliminate injury to tree roots, and which achieve higher returns on smaller investments. Investing appropriately in trees really is a 'no-brainer'.

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CELEBRATING OUR ICONIC RED GUMS THROUGH THE 'ECO-ARTS RED GUM TRAIL'

[1]Sam Middleton and [2]Natasha Davis

[1]Celebrating Red Gums, [2]Trees For Life

Abstract

Celebrating Red Gums is a community-founded movement to facilitate connection with the past, present and future River Red Gum landscapes of Australia. One of the projects emerging from this initiative is an Eco-Arts Trail. Through the use of technology, innovation and artistic mediums, the project proposes to immerse trail-goers in a journey which deeply connects people with Australia's iconic Red Gums.

Introduction

Originating in Southwest Victoria in 2015, **Celebrating Red Gums** began with a question:

"Could we, as a community, benefit from coming together to celebrate our affinity with these magnificent and iconic trees, and could this in turn help to ensure the endurance of Red Gums in our landscape?"

In answer, the community of Cavendish, on the banks of the Wannon River in the heart of the Southern Grampians *'Red Gum Country'*, developed and delivered the inaugural *Cavendish Red Gum Festival* in April 2018. The festival showcases "all things Red Gum", inspiring the stewards of our landscape, and the wider community to celebrate and value the many ways in which Red Gums enrich our lives.

Now scheduled as a biennial event, festival-goers are invited to grow and share their knowledge of environmental and habitat values, the Aboriginal cultural significance of Red Gums and the use of the sturdy timber by colonial settlers. Red Gum-inspired art, poetry, photography and music is featured, along with wood crafts and furniture, produce from the Red Gum landscape, and community creativity and wellbeing themes are explored.

Underpinning the Celebrating Red Gums initiative, is the concept of bringing to community consciousness, the largely uncelebrated notion that our 'Red Gum Country' bestows upon us a much greater gift beyond the tangible assets; it inspires us in a myriad of ways, and for many, it provides us with a sense of place, a sense of belonging…

A Sense of Home

In majestic isolation the mighty Red Gums stand
With roots intertwined throughout the fabric of our land
Heeding not the flying embers nor prevailing Southern winds
Their girth a living testament to fortitude within

They succour our marsupials, and shelter our prime flocks
Flourishing in clay and floods they seed amongst the rocks
Their canopy and crevices a home for birds and bees
Their snaggled roots prime habitat for native fish species

The lifeblood of an ecosystem flows within their veins
And when the life-force ceases, the fortress still remains
The pulsing of the ancient past echoes from their core
Scars depict the ancestry of those who came before

A living, breathing entity their graceful splendour reigns
Monumental in our landscape throughout times of recent change
And as I stand beneath and gaze into the peaceful dome
The mighty River Red Gum, gives to me, a sense of home

Sam Middleton

Why Red Gums?

Throughout the Celebrating Red Gums journey, it's a privilege connecting with a diverse range of people. Unsurprisingly, not once has anyone ever asked, "what's a Red Gum?" There's often a point in conversation, where a person 'lights up' and begins to tell their story of connectivity; about a particular tree in their yard, neighborhood or paddock, or a painting they love, or a piece of furniture they've admired. The significance of River Red Gums was so great to one gentleman, that he asserted they should be featured on our National Flag.

In 2016 and 2017, in addition to the Celebrating Red Gums social media page, a monthly e-newsletter provided another platform of opportunity for all who expressed a passion for the Red Gum landscape, to share their story of connectivity in a way which was meaningful to them. The newsletter had only a relatively small reach, but the stories submitted by landscape residents and custodians were unique and powerful representations of the core intent of the initiative.

"There's just something about a River Red Gum that makes you step back, take a moment and say, 'wow.' Just look at that tree!"

Excerpt from 'Omeo Park', David and Lyn Davis, Coonawarra, S.A.

"The old Beal are temples in the landscape. They are part of our country's spiritual heritage. They carry the memory, and true history of the land, and if we are ever to belong in a deep way, we must learn to listen to what they say."

Excerpt from 'Beal: Defining the Landscape', Neil Murray, Australian singer, songwriter, author and poet.

"Now after more than 40 years, the magic of the Red Gums still provokes deep emotions. The gentle giants are present with me each day. Reassurance that no matter what happens in life, life goes on."

Excerpt from 'Romancing the Red Gums', Jo Tully, Melville Forest, Victoria

Ochre pits, and stone-axe blaze
Then Mitchell and the bullock drays
Longboats on ***his*** *Glenelg River*
Mount William's winds made riders quiver
Two hundred years with us around
Settlers needed the red gums' ground
For sheep and crops and living space
We cleared them at a rollicking pace

So much waste!
What shocking haste!
Insensitive to their age and grace
Bloody base!
Mortised for a post-and-rail
Split and interlocked at Harrow gaol
And the shearing shed at Kout Narin
Gossamer fleece and shearers lean

Excerpt from 'Camaldulensis', Rob Youl

"For people like me who grew up amongst them but have moved away, nothing says 'home' like being back in the beautiful Red Gum country. It is wonderful to see Red Gums being rightly celebrated as one of the world's great trees."

Cavendish Red Gum Festival Ambassador, Professor Andrew Campbell, FAICD.

"I just love the gnarly, twisted shapes and the size of the trees standing in the paddocks and on the roadside, like guards over the countryside. There is always something reassuring when these trees come into view."

Ian Patience, Metamorphic Design

"As they bend around each injury, our Red Gum monuments show us how accommodating you have to be to endure and become a living antiquity. A lot of things in our museums are not as old as these ancient trees."

Excerpt from 'The vulnerability of an ancient landscape', MairiAnne Mackenzie, Ararat, Victoria






The Eco-Arts Red Gum Trail

Our vision for the Eco-Arts Red Gum Trail is an immersive, Geographic Information System (GIS) enabled, customisable trail network across the River Red Gum landscapes and assets of Australia.

About the Trail

To be piloted in South Australia, *The Trail* will employ artistic mediums to showcase, signpost and inspire participation via the creation of an interactive, educational and emotionally-connective self-drive, ride and/or walking trail network encompassing public roads, parks and spaces.

The project aims to immerse trail-goers in a journey which deeply connects people with Australia's iconic Red Gums. The trail experience will be GIS-enabled and App-delivered, with experiential inclusions in both the physical and digital realms. People may be inspired to engage with nature in ways which not only support their physical, mental and spiritual health and wellbeing, but which instil or reawaken a commitment to nurture our landscape and provide for the future.

By way of practical example of a potential trail inclusion:

Via the App., you elect to visit 'Significant Red Gums', in the Mitcham area, and from the available options, you are inspired to be guided to Brown Hill Creek's 'Monarch of the Glen'. At the tree, your iPhone/iPad then takes you on a journey of discovery, depicting the growth of that tree from a seedling to its current age. Through visual storytelling, as the tree matures, the landscape changes accordingly, portraying the Aboriginal and later colonial settler connection with the immediate environs.

A featured link provides access to further information on the history of the area.

You are then invited to photograph 'Monarch of the Glen', caption your experience, and share to a prescribed social media platform.

The benefits are boundless.
The Trail:

- Can grow organically; suburbs, towns and regional areas can nominate and develop/showcase their own Red Gum assets;
- Will appeal to many people in different ways, with a wide range of opportunities and experiences; people can engage in a way which "speaks to them";
- Enables individual, family or group engagement;
- Opens the door to cross-border collaboration and partnerships across landscapes;
- Value-adds to existing leisure, tree and produce trails, nature parks and reserves, galleries, museums, and Red Gum assets;
- Taps into emerging innovative technology, providing a platform of opportunity for creative expression and inclusion;
- Promotes community pride-of-place, community resilience, and wellbeing;
- Inspires nurturing of our landscape, and promotes knowledge and understanding of our environs.

The scope of the initiative encompasses the Environment, Arts, Tourism, Technology, Education and Health sectors, providing a platform to engage a diversity of talent in the development, delivery and maintenance of The Trail, with benefits back to our ecological infrastructure, economy, and community.

While The Trail will be perpetual, it shall also be dynamic and as unique as the Red Gums themselves.

Bringing the vision to life

Progressing from the preliminary conceptual phase of the project in late 2020, to the "let's nut it out" stage in 2021, the Eco-Arts Red Gum Trail has continued to inspire and engage the interest of a diverse range of subject matter experts, community members and organisations; with volunteers proffering their skills and knowledge to help grow the initiative.

Governance and Planning

As we move toward the establishment of Celebrating Red Gums as a legal entity, the initiative has the support of **TREENET Incorporated** to act as an auspicing body and 'banker' for incubation funds.

ForestrySA have generously provided sponsorship support, funding the costs of two workshops in 2021.

The Awesome Foundation (Adelaide Chapter) have recognized the merit of the Eco-Arts Red Gum Trail project concept with a grant, and

Effortless Web have kindly offered to build the Celebrating Red Gums website, at no cost.

An initial stakeholder workshop was held in late May 2021, facilitated by Vicki-Jo Russell AM, Chair of Nature Festival (SA) and Revegetation Services Manager at Trees For Life. Following this workshop, a Development Group has been formed to progress The Trail project in 'phases', as we explore opportunities to demonstrate the scope and benefits, and test the design, technology and content. The group are currently working on an initial Project Plan and investigating funding opportunities.

A large-scale workshop is scheduled for September 2021, bringing together a wider group of potential stakeholders, development and delivery partners and community members to further explore the way forward. This workshop will be professionally-facilitated by Matthew Wright-Simon, founder and Principal of Ecocreative, and hosted by Flinders University at their Victoria Square Campus, Adelaide, SA.

Developing the on-line infrastructure and content

As a community volunteer-based project, the Eco-Arts Red Gum Trail qualifies as a **Flinders University** Community Outreach Project, eligible for significant in-kind support. Flinders University's GIS Specialist and Spatial Database Manager, Rob Keane is leading the project's GIS Team in the development of both a crowd sourcing platform for data entry/collection, as well as aiding the development of a phone App for delivery. Flinders University will also host the data at no cost to the project, and student involvement will bring additional expertise and energy.

Development Group member, Dr Paul Koch, Future Ecosystems, is liaising with cutting-edge App developers and contributing to defining the desired attributes and functionality of the delivery platform.

Melbourne University's Christie Widiarto, Lecturer in Animation, Film and Television, VCA also envisages potential collaboration with her students. As well as expertise in creative content, Christie brings to the project a wealth of experience in successfully facilitating funding for community collaborative arts projects.

Enthusiastic project participants and community members are volunteering some wonderfully innovative content possibilities, and the large-scale workshop shall enable us to explore these suggestions, as well as capture further ideas.

Conclusion

What has been apparent from the outset is that this ambitious initiative has truly captured people's imagination, inspiring their support and participation; and even in this fast-paced world of juggling a multitude of commitments, people are stepping up to celebrate the past and present, and volunteering their energy to help shape the future of our extraordinary and iconic Red Gum landscape.

We look forward to your feedback and potential involvement with the development and implementation of The Trail over the coming months and years.

Enquiries: sam.middleton@bigpond.com

Photo Credits

Image montage

1. PS Marion, Dave Hartley Photography
2. Catherine carrying Alana and pregnant with Creina, Silvio Apponyi
3. Gumnut Beaver Vase, Brendan Stemp
4. Canoe Tree at Blanchetown, SA, 1988, Trevor Thomas
5. Ben Gurney's Bullock Team at Kalangadoo, 1800's, Nick Hunt
6. Kersbrook Red Gum, Aaron Poole

(Below) from

'The vulnerability of an ancient landscape', MairiAnne Mackenzie

DATA DOES GROW ON TREES (FORESTREE)

Ian Seccafien & Ben Seamark
City of Marion & Forestree

Introduction

In July 2020 the City of Marion purchased the Forestree tree management software to improve our service delivery and asset management of the trees under our care and control (council land). The system is highly capable and identifies each tree as an individual asset and works as a tool to provide whole of life works management. Our field staff, who had been using a generic asset management system previously, quickly found Forestree to be user friendly and, recognizing its benefits, embraced its implementation and use.

Embracing continuous improvement and corporate values around innovation, the Open Space Operations team was keen to ensure the system could work in sync with other corporate applications such as our Customer events system and broader GIS platform. Beyond this was a capability requirement to provide detailed data analysis to support the recently completed service review and whilst Forestree has some excellent reporting capabilities inbuilt we felt by connecting it to Microsoft Power BI we could gain greater insights into our operations through deeper levels of data analysis.

Within 6 months we realised the powerful data the system was giving us and to visually present this to council we created a webpage which ultimately became the Marion Tree Interactive. This was officially launched in June 2021.

Why Forestree was developed for Councils

Urban Forestry has changed considerably over the years with a greater focus on the benefits trees provide as a community asset and the way they are managed to maximise these recognized benefits.

Technology has now enabled Councils to map trees through the use of remote sensing (satellite or Lidar) and with this provided Councils with a greater understanding of canopy cover level, tree health, potential opportunities to plant as well as a number other indicators to help benchmark and prioritise efforts to increase greening.

Council trees are however a physical asset and decisions made in regards to their retention, removal or species type is largely determined by those decisions, made every day at ground level. These decisions are made by arborists, suppliers, contractors, community, landscape architects and a range of others all of influence the way Council trees are managed, that in turn influence the performance or benefits public trees provide and Council's ability to deliver greening targets.

Council managed trees are unlike any other Council assets. The number of trees a City Arborist manages typically exceeds all other Council assets combined, their value accumulates over time, their conditions change routinely based on variable environmental conditions, growing environment and cultural practices.

For a Council, managing such a diverse asset class does not negate those basic principles of effective asset management, which includes maximizing the asset performance or condition, managing its risk and through this understanding cost. Forestree was built to not only help Councils capture their tree assets and keep data up to date but to manage, monitor and share this information with others including those key decision makers who influence how these assets are managed. Forestree was designed through a recognition that a unique software solution was required to help Cities manage one of their most diverse, variable and valuable assets.

Since its launch in 2020 Forestree has gained wide adoption and recognition by progressive Councils of various size across Metropolitan South Australian and abroad, due its unique ability to address those key challenges Councils face in managing arguably their most valuable public asset.

Marion Tree Interactive (Marion - A Green City)

A presentation on the implementation of the *Tree Management Framework 2018-2022* was provided to council in February 2021 to review its success to date and identify future opportunities to better manage and increase our urban forest across the city. To help facilitate this session an interactive web page was created to showcase the data collected from the use of Forestree. Feedback from Elected Members present at the session was overwhelmingly positive and they requested the web page become the basis for a public portal that residents could visit to see information about the trees in their suburbs. The page was transformed into the Marion – A Green City https://trees.marion.sa.gov.au/ which was launched June 2021.

The portal consists of 5 pages which showcase information under the following themes:

- **Urban Forest Home Page** – The portal front page allows users to see the total number of trees in the city* with a breakdown of tree by suburb represented graphically. The map can be rotated, laid flat and zoomed in to show individual tree data. Clicking on any existing tree will show individual data attributes include species type (total number of this species across the city and order ranking), height, spread and Google Street View image. Users can search by street address to find their street to see the types of trees located there.
- **Planting** – When this page is selected the map of the council runs a visual graphic of every individual planting location which has occurred within the last 3 years. It shows the total number of trees which have been planted in that time with a breakdown by suburb represented graphically for residents to see how many trees their suburb has received. Select Future planting and this will expand to open a 7-year suburb planting plan and when each year is clicked on, will show only those suburbs we are looking to plant that year. Approved planting locations are shown in a different colour and can be clicked on so the user can see the species type selected for that location. A forward projection of how we project our tree canopy to increase is shown graphically and provides data calculations annually projected out to the year 2040**. Alternatively, this also shows our projected canopy decline if our planting targets are not met.
- **Watering** – When this page is selected the map of the council area runs a visual graphic of every individual tree currently on our watering program, with trees watered today pulsing in a light blue colour. This data updates every 15 minutes and is the first of its kind anywhere in the world. Users can click on an individual tree and see its entire watering history by date and time and the total amount of visits by our water tankers in a season and the total amount of water used. Our water is recycled storm water which is captured at the Oaklands Park Wetlands, injected into the aquifer and re-extracted for use. Trees are watered via two 9,000L water tankers***.
- **Works** – When this page is selected the map shows the operational works and inspections undertaken within the last 12 months. This is visually represented with different colours allocated by work type. Each type can be selected individually to filter out and only show that work type across the city. Inspection locations are shown separately, this map has been integral to changing public perceptions about our tree management and public perceptions about council works in general.
- **Species** – When this page is selected the map shows our top 10 tree species, this list is generated according to the total number of each type of tree species we have across the city with a separate colour assigned to each one. An individual species can be selected which filters out the others and shows their locations on the map. We often receive enquiries about our Jacarandas and this is way the public can easily see the streets they are on. Tree species are shown using common names for community understanding and some species/cultivars are grouped under generic titles to provide a greater understanding on population diversity.

The Marion Tree Interactive (Marion – A Green City) has been an exciting initiative to work on and implement. It has received many positive reviews from our Elected Members, internal stakeholders and members of the public. It has been demonstrated multiple times to external stakeholders such as Flinders New Venture Institute (Flinders NVI), South Australian Local Government Urban Forest Alliance and has received 1,500 hits publicly, including hits from Europe and the USA.

Power BI (Data Analysis/Dashboards)

A critical consideration when purchasing Forestree was the ability to undertake detailed data analysis on a daily basis to inform operational decision making and ensure staff are achieving their set program maintenance targets. Forestree has excellent inbuilt reporting capabilities however we wanted to take this to a far greater level of detail. The decision was made to link Forestree to the Microsoft Power BI platform and this was set up via an API with data transferring twice a day.

Eleven data dashboards have been created which allow us to interrogate the information at an individual user/crew level and benchmark targets for staff to achieve were established. Power BI takes data and displays this via charts and graphs to show how our programs are tracking and if these targets are being achieved.

Highlighting the key dashboards below I have provided a summary of each dashboards capabilities and tangible outcomes which inform our business decisions.

Work Orders – Provides the number of work orders generated versus completed, with a breakdown by suburb, month completed and works function actioned. We use this to show when our peak periods are to inform resourcing decisions around which suburbs to target our pruning activities in based on the type of works being undertaken.

Planting – Provides the total number of trees to be planted by year, total number of trees to be planted in each street and total number of species required for each year of planting. Further filtering and analysis can reveal house numbers which are to receive planting and number of trees required at street level. This informs budgets, reduces wastage and gives certainty to future stock ordering and procurement for planting contracts.

Watering – Provides the number of trees watered per day and sets a benchmark average of what can be consistently achieved within existing resources, provides individual watering numbers daily bay user and counts the amount of trees watered in each suburb each month. Additional filtering can bring this down to street level to see how often individual trees are being watered. This data was instrumental in showing how drastically under resourced we were to water the trees we were planting annually and based on the targets set how much additional funding was needed to ensure we could water sufficiently.

Block Pruning – Our Elected Members and senior leadership have indicated this is one of our most critical service delivery programs, to implement this program a base line time average has been set and agreed by staff for pruning each individual tree (7minutes per tree). This is based on time in motion studies undertaken during our service review and factoring different tree size variables. Daily average number of trees to be pruned has been set accordingly and the projects created in Forestree and allocated to the crew with start and finish deadlines. Dashboard shows total number of trees per suburb to be planted and how our team is tracking to complete this in time. This is visually represented by a speedometer type indicator with green, orange and red for tracking purposes. Daily number of trees pruned is recorded and number of trees pruned by street is displayed.

Reactive Works – Provides the total number of reactive style works our crews undertake, including the number of customer events we receive and our timeframes for completion versus those still to be completed. It shows the daily number of inspections and completed customer events and gives a monthly indication of works volumes which has shown significant increases in work during COVID lockdowns and after storm events or when tree branch failures have received media attention. Additional filtering can focus on works allocated to contractors by individual company and provide information about number of jobs allocated and timeframes for completion. We anticipate the data will show additional internal resources to meet our service level demands will be required in the near future.

Pruning Time – Based on a 7-minute individual tree pruning average we can calculate the amount of time it will take to prune every tree in every suburb in the entire council area. At the current count of 42,700 trees we calculate it will take 4.2 years to complete the program. The dashboard also displays this figure calculated by months, weeks and days. Additional filtering can show number of trees by suburb or street and we can identify pruning type by tree species.

It is hoped over time this will give us data on the species types and specific suburbs which require more frequent visits to undertake maintenance pruning, thus informing our decision making around which species we plant and better targeting our maintenance programs to reduce customer events being raised.

Conclusion - For many years the operational works divisions of council's have continued to absorb the increasing risk management, customer demand and service level expectations of our communities to ensure we can successfully maintain our urban forest. This has largely been expected to occur without understanding of the resources it takes to achieve this. The implementation of Forestree has given us a data capability unheard of previously in local government. For the first time in the operational space we can show with certainty the volume of work we undertake daily and the resourcing impact it takes to successfully maintain a viable urban forest.

In the initial phase of operations, we have been able to demonstrate the need for additional resources to water newly planted trees to ensure they successfully establish to meet tree canopy increase targets and employ an additional arborist officer to undertake inspections and better manage our existing trees. With councils around Australia currently planting thousands of trees to increase tree canopy this will inevitably result in a need to increase resources to manage these trees when they grow.

Most communities have little understanding of what it takes and the costs involved to meet this demand and data driven analysis and applications like the Marion Tree Interactive will tell this story in real time to inform the community about this.

Key Learnings - Implementing Forestree over the last 12 months has been uniquely challenging and rewarding, some of the key learning I have experienced are:

- **Identify Key staff to drive implementation** – Any business improvement/operational platform requires key staff to drive its implementation and success. Forestree is no different……however what makes this system stand out from the crowd is its ease of operation and its web based application. It can be installed on any device (Android/IOS) making it easily deployable in the field. It uses aerial imagery with high resolution which is updated every couple of months and its simplistic and uncomplicated data collection style means anyone can learn it easily.
- Engagement with internal stakeholders such as IT and GIS/SIS departments will be critical and it will be commonplace for these departments to be wary of a stand-alone 3rd party platform beyond their administrative control. What overcomes this is its ability to integrate seamlessly with corporate applications via proven API's and the local access controls granted to the council administrators to customise the system and export data at will. Any new change management process will cause concern and field staff may be wary and may not want to become involved. Claims of 'not my job' and *"this is spying on us"* are common. So to combat this I recommend getting them involved early on in the process, show them the data it can produce and the functionality of the system, take the time to answer their questions and show them how this can translate into additional resources to ease the workload on them.
- Data collection is now an essential tool in the kit bag of a professional Arborist and has become as common place as a chainsaw and secateurs.
- **Ongoing data administration (Who will do this)** – When we installed Forestree we had 36,000 trees in our database which we imported into the system, we now have 45,000 trees captured and this is increasing every day. By the time this goes to publication I would anticipate that number to be pushing 48,000. Daily data administration is a critical part of your organisations senior arborist or urban foresters role. As the asset owner they are best placed to undertake the ongoing management of the system and provide oversight of the data being collected to ensure appropriate levels of accuracy.

This needs to be factored into their capacity and some other daily functions will likely have to be delegated to free up time for them to take this on. Inevitable there will be local troubleshooting, administration, data cleansing and reporting which will need to be focused on. Service delivery projects and work allocation will need to be implemented via the system, staff will look to them to problem solve minor glitches with hardware and be available to listen to their suggestions on improvements or changes to the system. One of the best features of the software is it is locally customisable to meet local application needs and you as the administrator will take ownership to set this up and manage this.

- **Build the Application Program Interface (API)** – If you want to get the most from the system you need to connect it to other corporate systems. Forestree can connect to multiple corporate applications and the data generated can be implemented as above. It can also connect to customer event systems such as SalesForce and Technology One to allow customer requests to be allocated to individual staff and actioned in the field. If you want to access the full power of the system setting this up is a must and will prove hugely beneficial to your organisation.
- **Promote the value of what you do** – For the first time urban forest managers have a capability to showcase the dynamic work we undertake daily to ensure our communities have a healthy urban forest. The days of council workers leaning on a shovel are long gone but the perception is not. This data driven system is changing that and having a community portal where residents can see what tree work we are undertaking daily has been hugely beneficial. We have found they are becoming more receptive to our planting initiatives, want to become involved and we are slowly changing the negative perceptions around trees and the issues they cause.
- **There is no limit -** Realistically we have only scratched the surface of this and I believe there are huge improvements to come in the future as other corporate applications come on line. We have successfully incorporated Forestree into our Smart Cities initiatives and we are making the Marion Tree Interactive visible on smart message boards in our reserves. We are hoping to establish a volunteer program which will allow a citizen science aspect to collect and update data for us. Tree Watering will receive a higher level of focus and we partner with research groups to develop technology to better tailor make our tree watering programs. It also must be said we have only had Forestree for a small amount of time, just imagine what we can do with the data once we have capture two or three years' worth.

On a private note I am truly thankful to TREENET for the opportunity they have provided to showcase our recent accomplishments and I hope I have given you an insight into what we can achieve through technology and prove beyond doubt that **Data Does Grow on Trees**

**Mapping Data is incomplete and not every tree in the council area is on Forestree, mapping is still being collected daily with the web page updating its dataset twice a day*

***Percentages are based on Council owned Road Reserves & excluded Parks/Reserves. A number of factors are taken into account including, number of trees planted per year and mortality rates. The equation below provides an indication on how the projected percentage is calculate:*

(Current Canopy Coverage + (New Planted Trees - Planting Mortality Rate + % New Tree Grow) - Natural Canopy Decline)

****Watering capacity is being increased with the upcoming addition of 2 9,000L water tankers taking the fleet to 4 tankers overall, it is further anticipated that additional funds may still be required to undertake contract watering*

GREENER, COOLER AND MORE SUSTAINABLE COMMUNITIES: MANAGING THE URBAN FOREST INTO THE FUTURE USING GEOSPATIAL DATA.

S.J. Holt

Aerometrex

Abstract

Whether the value of the urban forest is defined by its socioeconomic benefits or its monetary value, paramount to the understanding of the importance of trees within urban environments is a quantitative understanding of how many trees there are and their spatial distribution throughout the community. City-wide assessments of urban tree canopy cover, e.g., McPherson et al., (2011), Jacobs et al. (2014) and S.J. Holt (2020), have become common foundations for national and local governments to measure, assess and increase the number of trees and green spaces within their government areas (Ordóñez et al., 2019). Accurate benchmarks and ongoing assessments of tree canopy cover and green spaces allow local government agencies to continuously review the performance of ongoing greening initiatives as well as ensuring that future policies are not only adequate, but achievable (Amati et al., 2017; Hurley, 2020)

Light Detection and Ranging (LIDAR) (**Fig. 1**) has become an industry standard remote sensing tool to map vegetation ecosystems (Coops et al., 2021) and quantify plant attributes and urban environments (Wang et al., 2019; Wang et al., 2020; Holt, 2020). Over the past year, Aerometrex has worked alongside urban environmental experts at the state and local government level to develop city-wide, LIDAR-derived tree canopy assessments, designed to provide a holistic understanding of the urban forest across large areas of interest and at a range of resolutions (council, suburb, property, or unit area) on both public and private land. Aerometrex urban forest data suite gives environmental experts and policy makers at all levels of government a critical understanding of the state of the urban forest at a given snapshot in time, while also providing them with the spatial and temporal context needed to value their green assets effectively and accurately.

Presented here are the results of three case-studies undertaken by Aerometrex utilising LIDAR to measure the characteristics and spatial distribution of the urban forest across large areas of interest:

i. Tree Canopy Coverage Benchmark, Metropolitan Adelaide, 2018/19 – Undertaken on behalf of The Department of Environment and Water (DEW) and metropolitan local government climate change adaptation groups with the aim of producing a city-wide benchmark for tree canopy coverage across Metropolitan Adelaide.

ii. City-wide plantable space assessment, Metropolitan Adelaide, 2018/19 – Commissioned by Green Adelaide and DEW to identify priority areas in greatest need of greening investment and inform future project design to provide the greatest benefit to the community.

iii. High resolution tree canopy change detection and classification, City of Unley, 2018-2021 – Carried out in collaboration with City of Unley to develop methodologies to quantitatively measure and accurately classify the changes in tree canopy between two epochs.

In combination, these case studies showcase the ability of LIDAR to quantify the urban forest and green infrastructure at the city scale, and measure how it is changing with time – all derived from a single data capture to provide the most robust yet cost-effective foundation possible for the valuation of green assets and measure their benefit to the community.

1. Introduction

Increasing urban greenness, vegetation and urban tree canopy cover has become one of the most critical considerations for strategic planning within state and local government organisations (Amati et al., 2017). Urban trees and community green spaces have been identified as an important tool that can be used by policy-makers to mitigate the many negative environmental effects of urbanisation (Roy et al., 2012).

Numerous studies have shown that the presence of urban trees can provide socioeconomic value to the community through numerous positive effects on the urban environment, such as economic benefits (Payton et al., 2008; Elmqvist et al., 2015; Donovan et al., 2019), positive effects on community health, well-being and safety (Kuo and Sullivan, 2001; McPherson et al., 2011; Kardan et al., 2015), improved air quality and storm water attenuation (Berland, 2012; Nowak et al., 2014; Selmi et al., 2016; Grey et al., 2018), combatting climate change through carbon sequestration (Brilli et al., 2019) and increasing community resilience to the effects of climate change by reducing the effects of urban heat islands (Tan et al., 2016; Rashid et al., 2020; Cheela et al., 2021). Translating the socioeconomic benefits of the urban forest into economic terms, which are often central to decision making processes and policy development, can be challenging (Rogers et al., 2017; Wang et al., 2018). Despite this, it can be advantageous to quantify the monetary value of trees as it enables a quantitative understanding of the balance of costs and benefits associated with green assets, leading to the effective integration of economic assessments into decision making processes at state and local governments (Jones and Davies, 2017; Song et al., 2018).

Whether the value of the urban forest is defined by its socioeconomic benefits or its monetary value, paramount to the understanding of the importance of trees within urban environments is a quantitative understanding of how many trees there are and their spatial distribution throughout the community. City-wide assessments of urban tree canopy cover, e.g., McPherson et al., (2011), Jacobs et al. (2014) and S.J. Holt (2020), have become common foundations for national and local governments to measure, assess and increase the number of trees and green spaces within their government areas (Ordóñez et al., 2019). Accurate benchmarks and ongoing assessments of tree canopy cover and green spaces allow local government agencies to continuously review the performance of ongoing greening initiatives as well as ensuring that future policies are not only adequate, but achievable (Amati et al., 2017; Hurley, 2020). For a city-wide assessment of the urban forest to yield actionable results, it is critical that it accurately accounts for trees on private as well as public land, as private land can account for over 50% of both urban tree cover and open space, thus, making a large contribution to the urban forest and it's positive benefits (McPherson, 1998; Fuller and Gaston, 2009; Schmitt-Harsh et al., 2013; Klobucar et al., 2020).

Light Detection and Ranging (LIDAR) (**Fig. 1**) has become an industry standard remote sensing tool to map vegetation ecosystems (Coops et al., 2021) and quantify plant attributes in both native vegetation (Van Leeuwen and Nieuwenhuis, 2010; Li et al., 2015; Hagar et al., 2020), managed forests (Silva et al., 2016; Dalla Corte et al., 2020; Leite et al., 2020) and urban environments (Wang et al., 2019; Wang et al., 2020; Holt, 2020). LIDAR is often preferred to other passive and active remote sensing technologies (e.g. Synthetic Aperture Radar, SAR) for the purposes of measuring vegetation as LIDAR provides greater sensitivity to changes in vegetation structure (Dong and Chen, 2018b). LIDAR-derived metrics can also provide a more accurate description of the canopy coverage and be more sensitive to small-scale changes than random point classification methods such as iTree (Parmehr et al., 2016). Furthermore, LIDAR can provide greater positional accuracy and three dimensional detail compared to AI-derived canopy maps (e.g. Abdollahi and Pradhan, (2021)) as LIDAR measures the vegetation explicitly in three dimensions, free of perspective effects (Dong and Chen, 2018a).

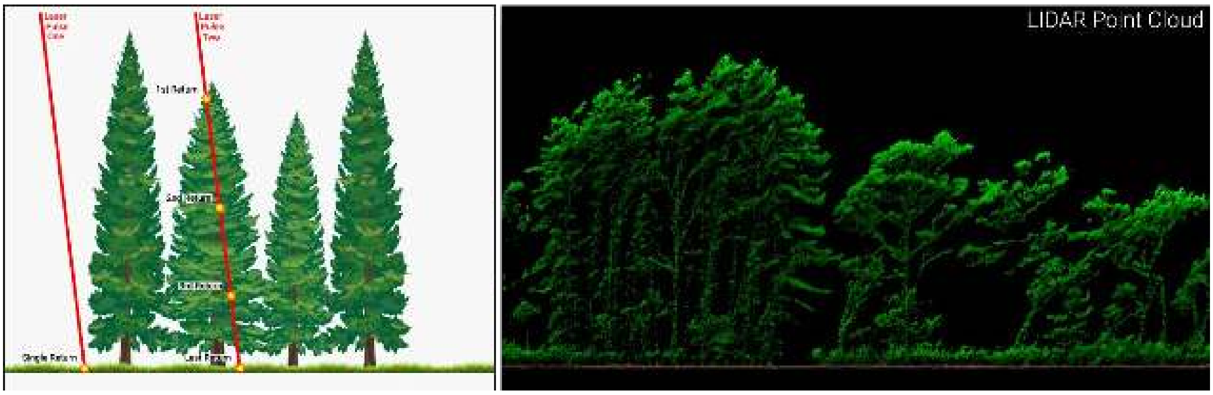

Figure 1 *- LIDAR explicitly images the landscape in three dimensions by measuring the time taken for a laser pulse to travel from the sensor in the aircraft, to the ground surface, and for the pulse to be reflected back to the sensor. LIDAR pulses have the ability to penetrate tree canopy and map the internal structure of the tree (left) to produce an accurate three-dimensional point cloud model of the vegetation (right).*

Over the past year, Aerometrex has worked alongside urban environmental experts at the state and local government level to develop city-wide, LIDAR-derived tree canopy assessments, designed to provide a holistic understanding of the urban forest across large areas of interest and at a range of resolutions (council, suburb, property, or unit area) on both public and private land. Aerometrex urban forest data suite gives environmental experts and policy makers at all levels of government a critical understanding of the state of the urban forest at a given snapshot in time, while also providing them with the spatial and temporal context needed to value their green assets effectively and accurately.

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In combination, these case studies showcase the ability of LIDAR to quantify the urban forest and green infrastructure at the city scale, and measure how it is changing with time – all derived from a single data capture to provide the most robust yet cost-effective foundation possible for the valuation of green assets and measure their benefit to the community.

2. Project Datasets

All three case studies presented here utilize LIDAR data captured using a RIEGL VQ-780i sensor, with a vertical accuracy of 10cm and classified to Aerometrex's Type 2 standard (**Fig. 2**), which includes manual refinement of the ground, building and high vegetation classes (ASPRS, 2019). The 2018 LIDAR survey used in all three case studies was captured in April 2018 and was expanded to include full coverages of sixteen metropolitan councils in November 2019. In total, the dataset covers 1,706 km^2 of metropolitan Adelaide (**Fig. 3**). The third case study incorporates a subsequent LIDAR capture in April 2021 across City of Unley (14.5km^2) and is compared to the 2018 data across the same area to quantify change detection. Both datasets have a minimum point density of – 8-12 $pts.m^{-2}$. For all projects, following consultation with council representatives, a tree was defined as any vegetation above three metres in height, as it is above this height that the tree begins to provide shading.

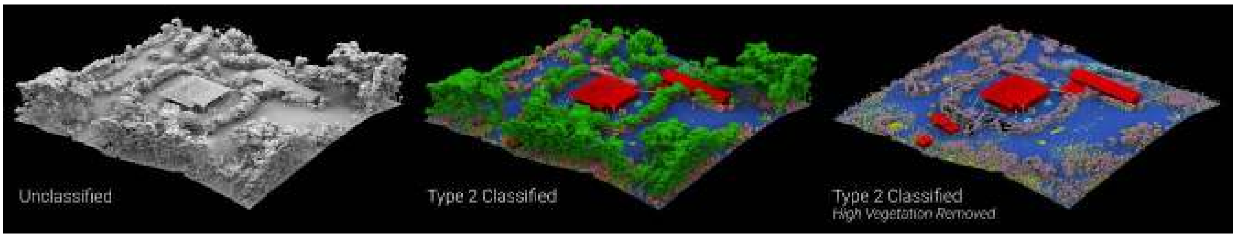


Figure 2 *– Left: unclassified point cloud visualised using ambient occlusion (REF). Middle: Type 2 classified point cloud with ground (blue), low and medium vegetation (yellow and pink), high vegetation (green), building (red) and unclassified (aqua). Right: the same classified point cloud with the high vegetation class removed.*

Figure 3 *– Left: Map showing the full coverage of the 2018/19 LIDAR capture (green) as well as the area covered by the City of Unley 2021 capture.*
Top: a zoomed in view of the urban area covered by the 2021 LIDAR survey.

3. Case Study 1 – Tree Canopy Coverage Benchmark, Metropolitan Adelaide, 2018/19

3.1 Project Summary

In 2019 Aerometrex was commissioned by DEW and four metropolitan local government climate change adaptation groups (representing sixteen individual councils) to produce a quantitative tree canopy coverage benchmark across metropolitan Adelaide. The core aim of this project was to provide all participating LGAs and the State government with a quantitative, spatially explicit benchmark for tree canopy coverage in 2018/19. This benchmark would then form the foundation for the assessment of the effectiveness of greening initiatives across the city in coming years. As part of this project Aerometrex developed a suite of LIDAR-derived urban forest datasets (**Fig. 4**) to provide each participating council with not only a tree canopy coverage benchmark, but also an understanding of the vertical distribution of tree canopy (Canopy Height Model & Stratification Maps), the distribution of tree canopy across land ownership and land use types as well as a measure of the spatial distribution of tree canopy coverage across the city, independent of biases associated with measuring at the per council or per suburb level (Tree Canopy by Unit Area). The full set of results and associated graphical reports can be viewed at DEW's Urban Heat and Tree Mapping viewer (Enviro Data SA, 2021).

3.2 Methodology

The geoprocessing methodology used to extract all tree canopy metrics from the LIDAR point cloud were based on those presented in Dong and Chen, (2018b) and Holt (2019). Land Use and Land Ownership statistics were generated using parcel definitions provided by Department of Planning, Transport and Infrastructure.

3.3 Results

Tree Canopy Height

The city-wide Canopy Height Model (CHM) for trees above three metres in height revealed that the average tree canopy height across metropolitan Adelaide is 10.1 m with a standard deviation of 5.5 m (minimum height of three metres). The highest non-native tree canopy can be found in Bone Gully Forest, Kangarilla and the tallest native vegetation can be found in the Boulevard of Gums, Belair National Park, Mitcham (**Fig. 5**), which are 48.3m and 48.2m above ground respectively. Canopy Stratification Maps for all sixteen participating LGAs show that tree canopy between three and ten metres in height constitutes the majority of tree canopy cover across the city (**Fig. 5**).

Tree Canopy Coverage

The overall tree canopy cover for the metropolitan Adelaide area (as defined by (Holt, 2020)) for 2018/19 was 23.37% (**Fig. 6**). The tree canopy coverage for local government areas wholly within the LIDAR capture area ranges from 48.81% in City of Mitcham to 9.89% in the City of Port Adelaide Enfield. The average tree canopy cover across all participating LGAs was 23.16%. The tree canopy cover for suburbs wholly within the LIDAR capture area ranges from 71.8% in Waterfall Gully to 1.7% at Parafield. When measured by unit area, the average tree canopy coverage across metropolitan Adelaide is 22.7% within a standard deviation of 23.0%. For twelve out of the fourteen LGAs within the survey area, the majority of tree canopy covers residential land use areas and private land ownership areas. In some cases, as much as 50% of the tree canopy exists on residential or private, e.g. City of Unley, Town of Walkerville and City of Onkaparinga.

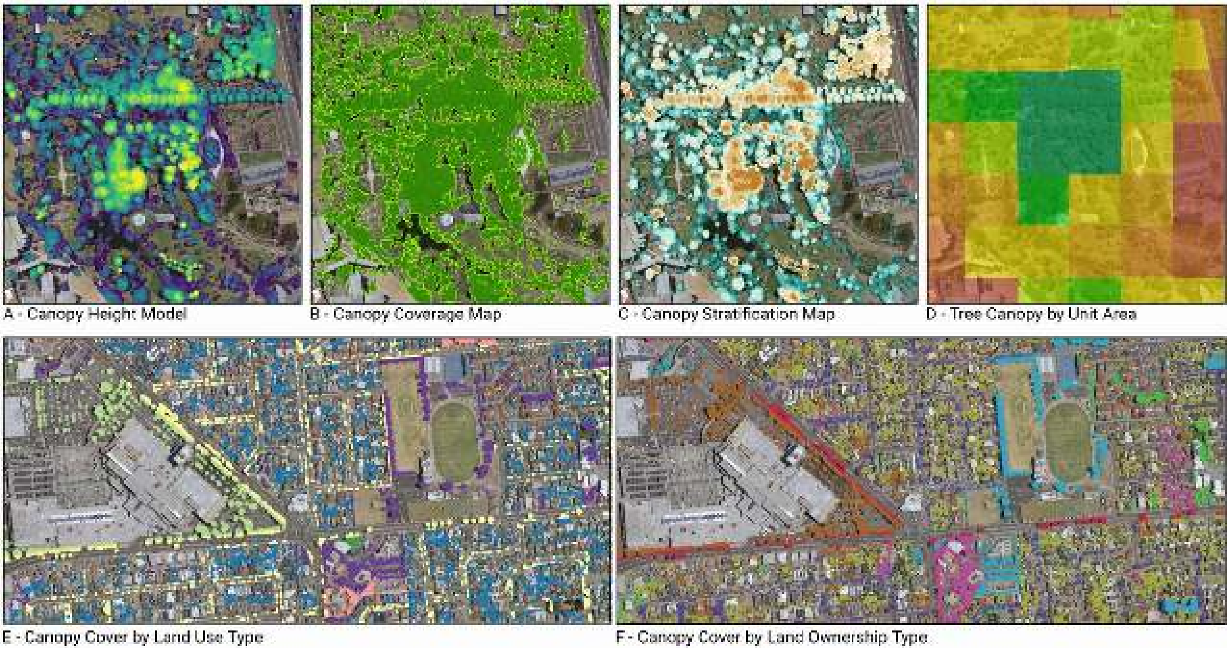


Figure 4 *– Top: The four key products that comprise Aerometrex's urban forest data suite. A: Canopy Height Model (CHM), a discontinuous raster showing the height of tree canopy above ground. B: Tree Canopy Coverage, showing the precise area covered by tree canopy. C: Canopy Stratification, showing the coverage of tree canopy within defined height strata. C: Canopy Cover by Unit Area, showing the percentage tree canopy coverage per 100 m by 100 m unit area cell. Bottom: Tree Canopy Cover by Land Use and Ownership generated by intersecting Tree Canopy Cover will parcel boundaries.*

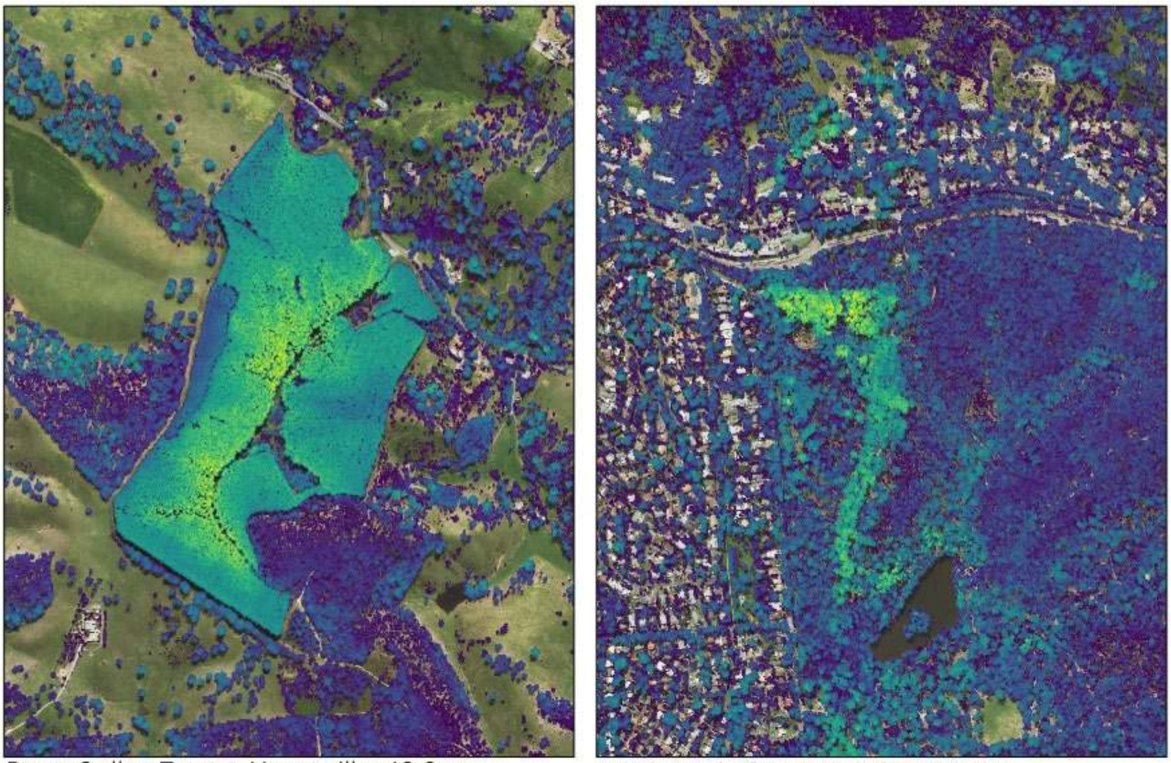
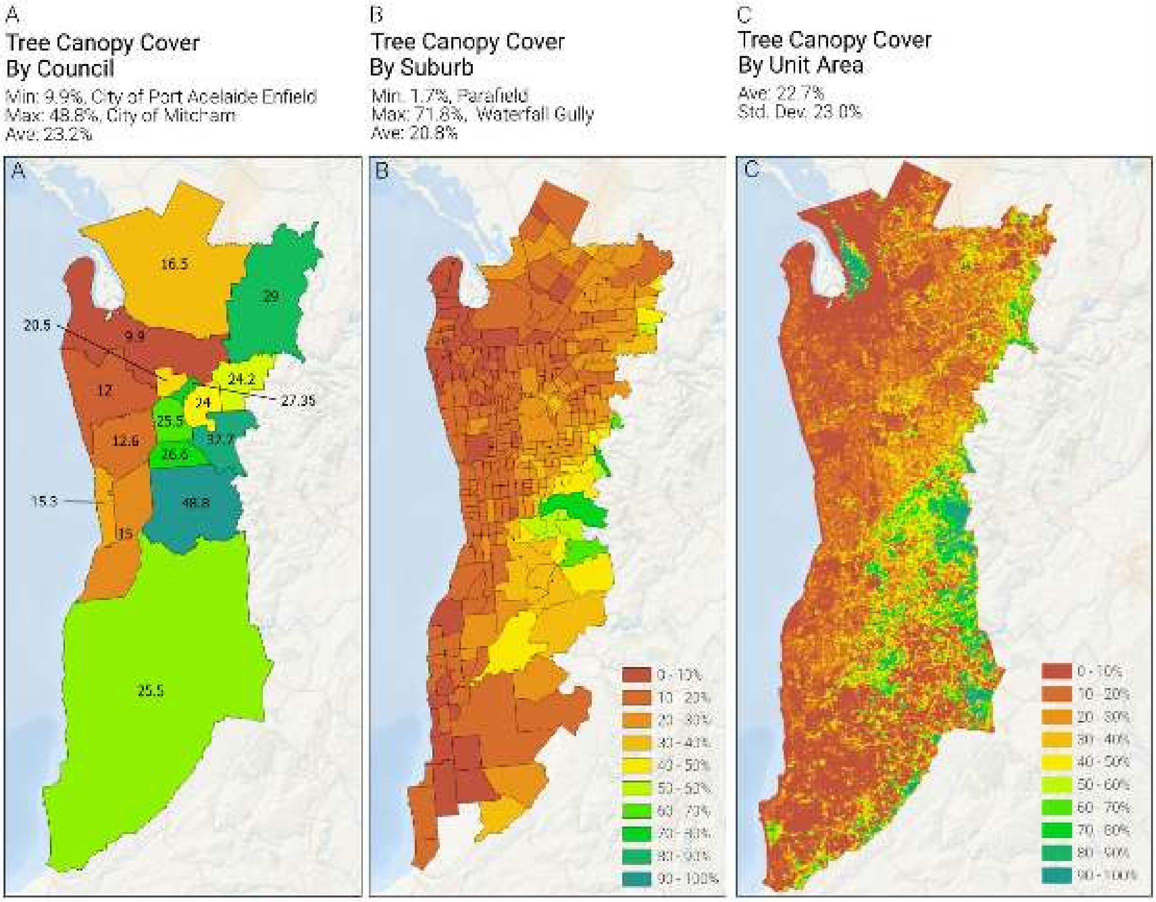


***Figure 5** – CHM of the tallest non-native and native tree canopy in metropolitan Adelaide.*
Left: non-native vegetation in Bone Gully Forest. Right: native vegetation in Belair National Park.

3.4 Key Project Outcomes

This project provided accurate, spatially explicit LIDAR-derived tree canopy coverage benchmarks for metropolitan Adelaide (23.37%) as well as individual benchmarks for all sixteen participating LGAs. The datasets provide both the State and local governments in South Australia with a nationally leading, spatially explicit benchmark that can be used to track the change in tree canopy coverage in years to come and assess the effectiveness of ongoing greening initiatives. When assessing the tree canopy cover by LGA extent or suburb extent, the true distribution of tree canopy can be hidden due to areas associated with coarse sampling domains (Dark and Bram, 2007). Added to this, the tree canopy cover of any given LGA extent is biased by the land uses within it. For example, the tree canopy coverage in the City of Mitcham is positively biased by abundant national parks and reserves and the City of Onkaparinga's is negatively biased by arable agriculture. Canopy Cover by Unit Area provides an unbiased representation of the tree canopy cover and a robust description of the spatial distribution of tree canopy cover across the city, also allowing for a better understanding of the representative tree canopy coverage of denser urban areas, in this case 0-20%. The tree canopy by land use and land ownership results provide quantitative evidence of one of the key challenges facing LGAs: that despite being tasked with increasing tree canopy cover to meet greening targets, in many cases they do not control enough of the tree canopy to meet those targets. This highlights the critical role that private landowners play in increasing the tree canopy cover across the city and the importance of initiatives that target public awareness of urban greening initiatives (Ordóñez-Barona et al., 2021).



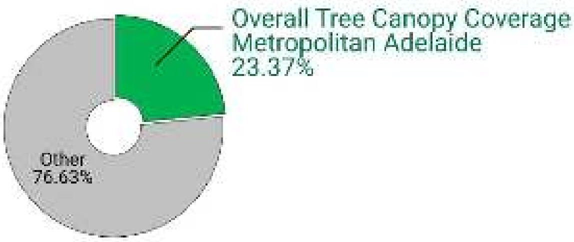


Figure 6 *– Distribution of tree canopy coverage across Metropolitan Adelaide, measured per LGA area (A), Suburb wholly within the LIDAR survey (B) and per 100 m by 100 m unit area. The overall tree canopy coverage for metropolitan Adelaide for 2018/19 was 23.37%. Base-maps: NWA, Geoscience Australia, Esri.*

4. Case Study 2 – City-wide plantable space assessment, Metropolitan Adelaide, 2018/19

4.1 Project Summary

The primary objective of the project was to produce a 50cm resolution, fully semantic classification of permeable and impermeable surfaces across 1,305 km^2 of metropolitan Adelaide (Holt, 2021). Green Adelaide and DEW funded the project to allow experts to use the permeable and impermeable surface data to form a detailed understanding of the amount and spatial distribution of plantable space (permeable ground surfaces), assess the progress and feasibility of current greening initiatives, and develop better informed targets and policies for the coming years. When combined with the 2018/19 tree canopy benchmark, these datasets can be used to not only identify areas in greatest need of greening investment, but also identify areas with the greatest greening potential and inform the development of long term greening policies (Wu et al., 2008; Bravo-Bello et al., 2020). Extending the classification into a full semantic classification of the urban environment meant that the final output could also be applied to detail surface water run-off and flood modelling during high rainfall events (Sugg et al., 2014; Sarkar Chaudhuri et al., 2017; Hung et al., 2018).

The final project output, consisted of a 50cm resolution semantic classification of the urban environment, comprised of five classification classes (developed in collaboration with government end-users):

1. *Impermeable* – impermeable ground surfaces such as pavement, concrete and roads.
2. *Permeable/Plantable Space* – permeable ground surfaces including bare soil and grass.
3. *Impermeable Above-ground Object* – Above ground features that are deemed to be impermeable in nature including buildings, tree canopy overhanging roads and other infrastructure between 0.25-3m in height with a relative NDVI below 0.15.
4. *Permeable Above Ground Object* – Above ground features that are deemed to likely be permeable in nature including trees and vegetation between 0.25-3m in height with a relative NDVI above 0.15.
5. *Water body* – Including the ocean, lakes, rivers, dams and large pools.

4.2 Methodology

Figure 7 outlines the methodology used to produce the permeable vs impermeable surface classification. The project utilised two key datasets, a set of LIDAR-derived raster inputs including a normalized digital surface model (nDSM) and intensity map, as well as four band multispectral imagery (R:G:B:NIR) captured near simultaneously to the 2018/19 LIDAR dataset. These datasets were combined with secondary, vector feature datasets used to refine the classification, including LIDAR-derived building footprints, tree canopy cover and waterbodies and AI-derived road extents. The semantic classification was carried out in two stages. Stage One (**Fig. 7**) consisted of classifying ground surfaces as either permeable or impermeable using an end-to-end trained Feature Pyramid Network (FPN) (Lin et al., 2017). Stage Two utilized the secondary vector feature datasets in a rule-based, Object Based Image Analysis workflow (Blaschke, 2010) to produce a refined sematic classification (**Fig. 7**).

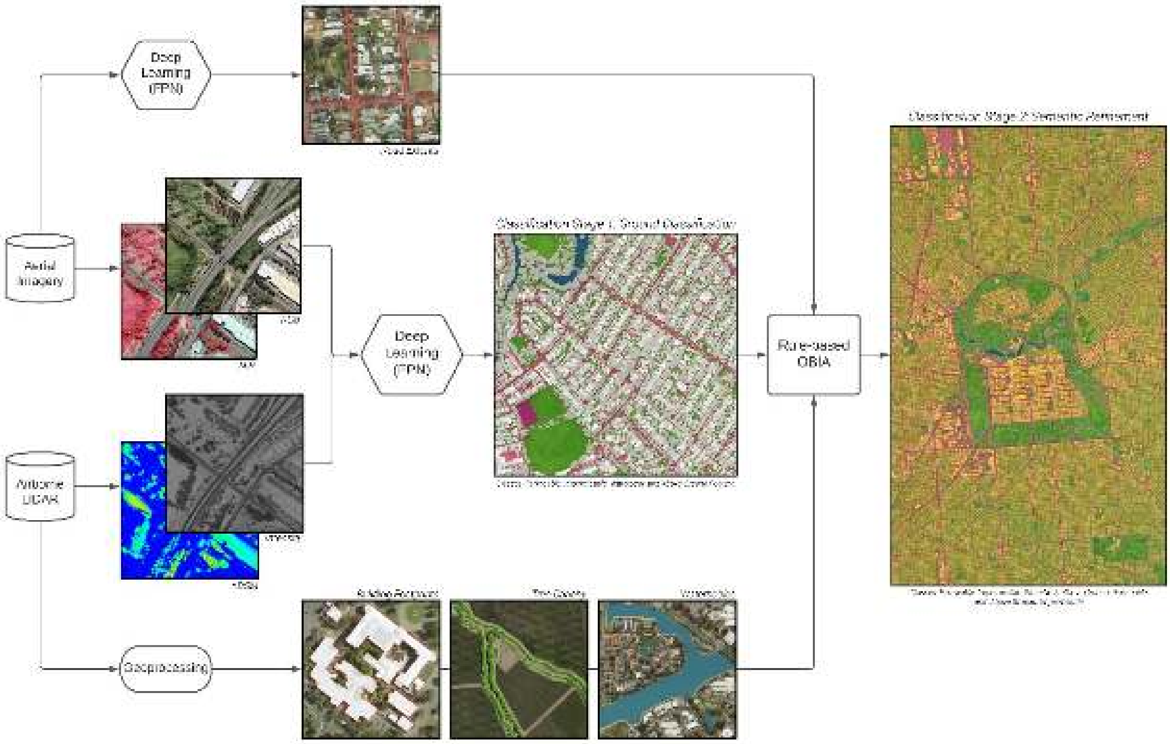


Figure 7 *– Graphical workflow showing methodology used for the two-stage semantic classification of Permeable surfaces (Plantable Space) and Impermeable surfaces, across the study area.*

4.3 Results

Classification Accuracy

The performance and accuracy of the FPN classifier was assessed using a manually labeled validation dataset which consisted of 10 separate tiles, each with an area of 1 km^2. Ground and above ground objects within each validation tile were manually classified using an Object Based Image Analysis workflow, utilising our high-resolution imagery as a reference (spatial resolution of 7.5cm). In total, over 27 million pixels were manually labeled, corresponding to an approximate area of 7km^2. A direct comparison between the classification of each pixel in the validation dataset and classified dataset was used to assess the performance of the FPN classifier. It is important to note that the data used for validation was not part of the data used to train the FPN classifier. The FPN-derived ground classification has an overall accuracy of 89.45% and an overall Kappa Index of Agreement of 0.78 (Excellent; Richards, (1999)).

Permeable vs Impermeable Surface Distribution

Figure 8 shows an example of the output classification, as well as the distribution of permeable and impermeable surfaces within the 2018 LIDAR survey extent, which covers the majority of Adelaide's urban areas and corresponds most closely with the capture date of the aerial imagery used in Stage 1 of the classification. 37% of Adelaide's urban area is permeable ground (plantable space) and 19.8% is impermeable surface (e.g. roads and pavement), and when combined with above ground impermeable surfaces (e.g. buildings), 44% of Adelaide's urban area is impermeable and would contribute to surface water accumulation. At the suburb scale (**Fig. 9**), the proportion of total suburb area that is plantable space, ranges from 78.0%% in Parafield (3,459,041 m^2 plantable space) to 6.4% in Mile End South (42,671 m^2 plantable space), with an average of 27% across all suburbs. The areas with the lowest proportions of plantable space are concentrated within a ~4.5 km radius of the Adelaide CBD (**Fig. 9**). Within the 2018 LIDAR survey area, the three land ownership categories that contribute the most to the total amount of plantable space are Private land (30.8%), State Government land (20.0%) and Local Government land (16.2%).

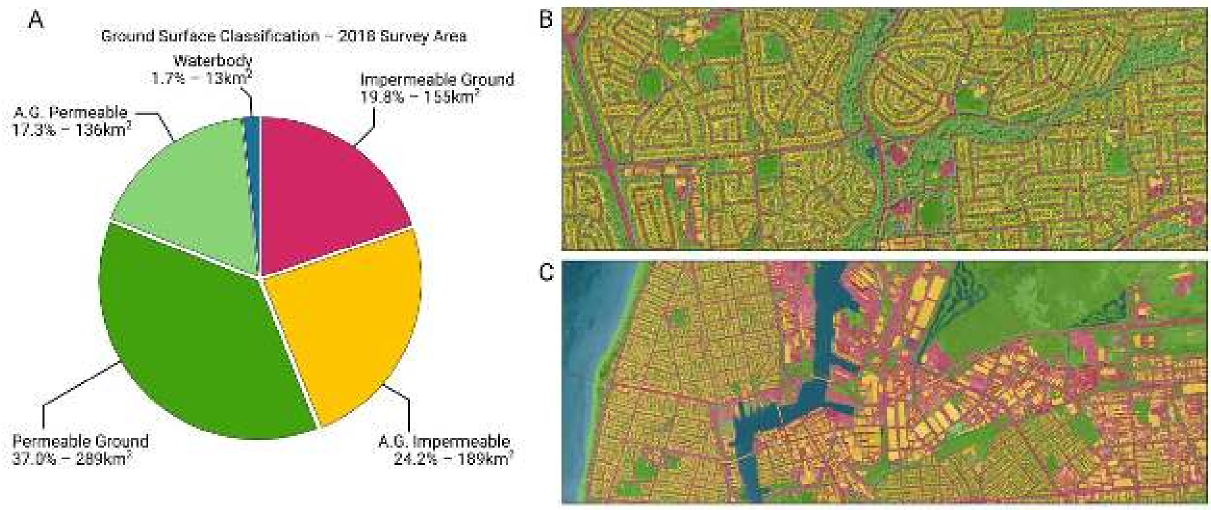


***Figure 8** – A: Statistical breakdown of the distribution of permeable (plantable space) and impermeable surfaces across the 2018 LIDAR survey extent. B: Example output of the classification from Redwood Park. C: Example of the classification from Port Adelaide and surrounds. Note: classification colour codes are constant across all three images. Modified from Holt (2021).*

4.4 Key Project Outcomes

Mapping the amount and spatial distribution of plantable space across the most heavily urbanized areas of metropolitan Adelaide provides much needed spatial and temporal context to the 2018/19 tree canopy benchmark and the value of the urban forest in certain areas.

By directly comparing the amount of tree canopy coverage within a suburb, as well as the proportion that suburb that is plantable, it is possible to understand the 'greening potential' of that suburb as well as the relative importance of preserving existing trees. **Figure 10** shows a bivariate plot of the proportion of plantable space versus the overall tree canopy cover for all suburbs wholly within the 2018 LIDAR survey area. Each of the four regions define the vulnerability and potential of the urban forest in each suburb. 'Ideal' suburbs have high tree canopy cover and high proportion of plantable space, meaning lots of existing trees and lots of space to plant more. 'High Greening Potential' suburbs have low tree canopy cover and high plantable space, i.e. few trees but ample space to plant more given effective planting strategies. 'At Risk' suburbs have high tree canopy cover, but very low proportion of plantable space, meaning that the existing trees need to be protected as there is little plantable space to replace trees lost to urban infill. Finally, 'Code Red' have low tree canopy cover and low plantable space. 76 suburbs are ideal, 151 suburbs have high greening potential, 44 suburbs are at risk and 38 suburbs are code red. It is these 38 suburbs that should be targeted in greening initiatives and policy development/reform as they have very few trees and very little space to plant more. Whatever the vulnerability or potential of the urban forest, private landowners will play a central role in the success of any planting initiatives given that the majority of plantable space resides on private land.

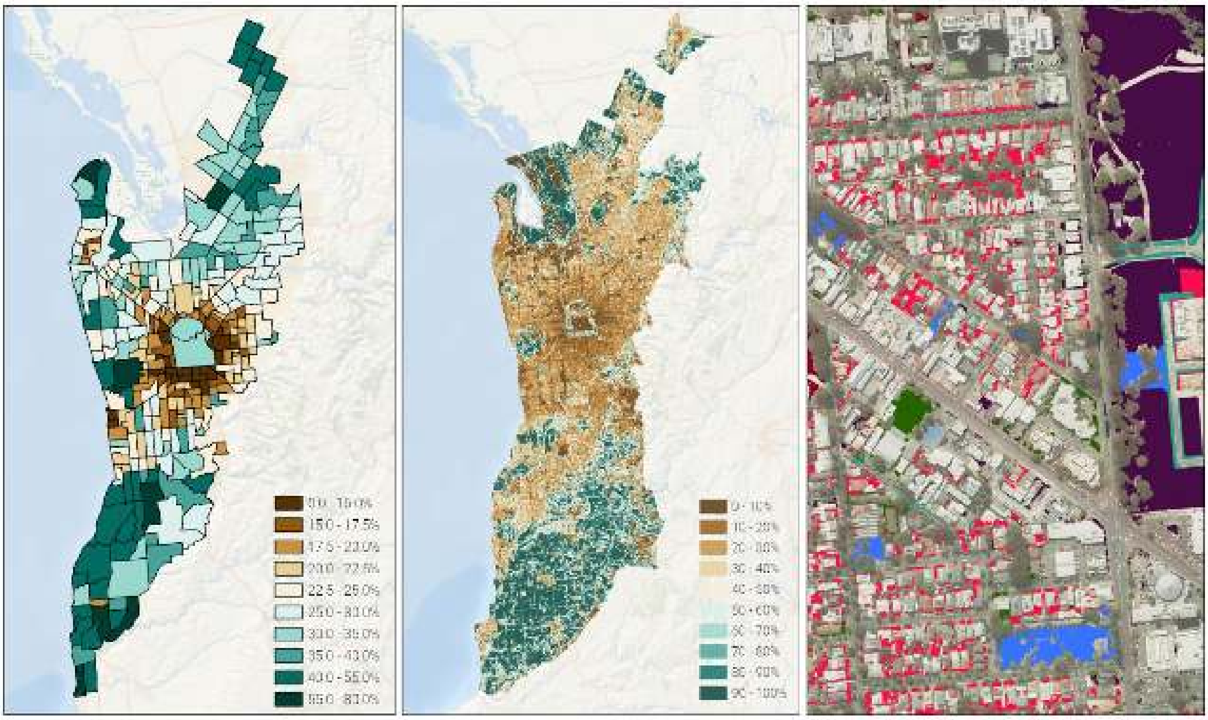


Figure 9 *– Left: The proportion of plantable space for each suburb wholly within the 2018 LIDAR survey extent. The suburbs with the lease amount of plantable space are concentrated in a 4.5km radius of the CBD. Centre: The proportion of plantable space per unit area (100m by 100m) across the 2018 LIDAR survey extent. Right: An example of plantable space classified by land ownership type, where red denotes Private Land, blue denotes Local Government land, light green denotes Local Government Road and dark green denotes Community Land. Left & Right Base-map: NWA, Geoscience Australia, Esri.*

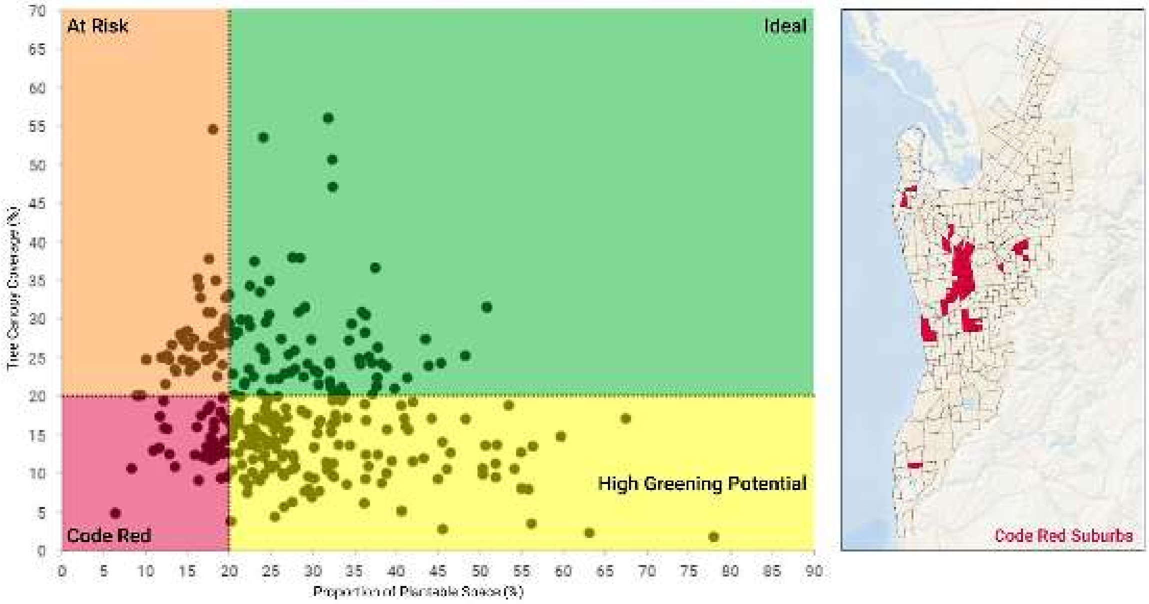


Figure 10 *– Left: A bivariate plot showing the proportion of each suburb that is plantable space, compared to the tree canopy coverage of that suburb. Right: a map showing the distribution of 'Code Red' suburbs. Right Base-map: NWA, Geoscience Australia, Esri*

5. Case Study 3 – High resolution tree canopy change detection and classification, City of Unley, 2018-2021

5.1 Project Summary

City of Unley commissioned Aerometrex to capture LIDAR across the LGA in April 2021 to produce a full urban forest assessment and provide an updated tree canopy coverage. This could be compared to the 2018 benchmark to quantitatively the measure the change in tree canopy cover over three years. A detailed investigation into the types of changes that were occurring to the tree canopy was used to gain a better understanding of what processes were contributing most to measured tree canopy gain and/or loss.

5.2 Methodology

All analyses used within the 2018/19 benchmark study were repeated, with the same input parameters and resolutions in order to produce datasets that were directly comparable to previous results. Additionally, Aerometrex utilised newly developed image segmentation and OBIA workflows to produce high-resolution (10cm) tree canopy coverage maps, for both the new 2021 LIDAR data and the historical 2018 dataset, to classify the changes occurring to the tree canopy across City of Unley. Isolated occurrences of tree canopy loss and gain were classified as Tree Planting and Tree Removal respectively. Areas of gain and loss greater than $4m^2$ and joined to an area of no-change (pre-existing tree canopy), were classified as Tree Growth and Pruning Reduction respectively. Areas of change less that $4m^2$ in area and joined to pre-existing canopy were left unclassified to remove noise associated with tree movement between and during captures. High resolution aerial imagery was used as a validation dataset and to provide an understanding of the changes in the urban environment that were driving tree canopy loss and gain. The spatial distribution of tree canopy losses and gains were assessed using standard and weighted hotspot analyses based on the Getis-Ord Gi* statistic (Ord and Getis, 1995; Getis and Ord, 2010).

5.3 Results

City of Unley Tree Canopy Cover

The repeat analysis of the urban forest across City of Unley showed that the average change in canopy height was 0.4m, the overall tree canopy coverage (measured at 1m resolution) has increased by 1.37% to 27.99% since 2018 and the largest increase by area in tree canopy coverage occurred in canopy between 3m to 10m in height.

As with the 2018 study, Residential and Private land contribute most to tree canopy cover. When measured at 10cm, the overall tree canopy coverage is refined by 4-5% for each epoch, 21.66% and 23.05% for 2018 and 2021 respectively, but critically the tree canopy change is +1.39%, only a 0.02% difference when compared to the 1m resolution dataset.

Tree Canopy Change Classification

Very high-resolution tree canopy maps for both epochs provided a robust comparison for the classification of tree canopy change (**Fig. 11**). Of the total gain in tree canopy cover, existing tree growth contributed five times the amount of new canopy (306,142 m^2) than newly planted trees reaching 3m in height (62,109 m^2), and solely offsets the total tree canopy loss, both by pruning reduction and tree removal (172,673 m^2 and 127,244 m^2 respectively). The average contribution of new tree canopy by a newly planted tree reaching 3m in height is 3.8 m^2 and the total area of increase due to tree planting is the equivalent of 16,344 new trees at 3m in height. The total contribution of existing tree growth and total canopy loss is the equivalent of 80,563 and 78,925 new trees at 3m in height respectively.

5.4 Key Project Outcomes

The effect of data resolution on greening target assessment

Comparisons between the overall tree canopy cover and change in tree canopy cover measured at two different resolutions (1m and 10cm) show that the value for the overall tree canopy coverage can be 4-5% larger when measured at coarser resolutions as compared to fine resolutions, however the change in tree canopy cover is constant, independent of resolution. These results indicate that the precise wording used when defining an LGA's greening target can have an effect on what resolution data is appropriate to assess that target. For example, greening targets such as "reaching 30% tree canopy cover by the year 2030" require high-resolution datasets which provide precise, refined tree canopy coverages. In comparison, greening targets such as "increasing tree canopy cover by 30% by the year 2030" can be assessed using coarser resolution datasets as the change over time is accurately measured regardless of resolution.

***Figure 11** – Example of high-resolution LIDAR-derived tree canopy change detection and classification form within City of Unley.*

Implications on Urban Forest management in City of Unley

The large-scale contribution of new tree canopy cover due to the growth of existing trees, as compared to newly planted trees, suggests that preserving and protecting existing trees is of critical importance alongside planting initiatives if City of Unley is going to continue to increase the amount of tree canopy coverage in the future.

The average area of tree canopy lost per tree removal is 11.8 m2, three times the average contribution of new canopy due to newly planted trees. This highlights the importance of protecting existing trees, because as the contribution of existing tree growth is reduced through tree removal, losses in tree canopy cover will rapidly outpace the contribution of newly planted trees. Weighted Hot Spot Analysis shows that the four most statistically significant clusters of large magnitude canopy loss occur at sites of urban development (Fig. 12). This would suggest that urban development and associated urban infill pose the greatest threat to the urban forest within the City of Unley.

6. Conclusions

The three case-studies presented here showcase the power of geospatial data such as Airborne LIDAR to produce city-wide urban forest assessments which quantify the amount and spatial distribution of both tree canopy cover and plantable space, as well as explicitly measuring and classifying tree canopy change with time, across both private and public land. City-wide LIDAR-derived tree canopy and plantable space studies provide critical spatial and temporal context to the process of valuing the urban forest, whether that value is defined by monetary value or socioeconomic benefits. Large-scale urban forest assessments will play an increasingly important role in helping environmental management experts and policy makers at all levels of government build greener, cooler, more sustainable cities and increase the community's resilience to the ongoing negative effects of climate change.

The results of each of these analyses highlight two critical considerations for environmental management experts across Adelaide:

1. Private landowners will play a critical role in helping build a greener, more sustainable future for Adelaide as the overwhelming majority of both existing tree canopy cover and available plantable space resides on privately owned land.
2. Preliminary tree canopy change detection and classification at the LGA level over the last three years following the 2018/19 benchmark suggests that growth of existing trees contributes a much larger amount of new tree canopy than newly planted trees. Given the time lag between planting and major tree canopy contribution, it is critical that local governments preserve existing tree canopy cover by protecting existing trees from urban developments and infill.

***Figure 12** – Aerial imagery from the location of the four most statistically significant clusters of large-scale tree canopy loss between 2018 and 2021 in City of Unley. For each image pair, the top image is captured in 2018 and the bottom is captured in 2021, with tree canopy loss vectors (both Pruning Reduction and Tree Removal) overlain in red. In each case the tree removal is associated with developments and urban infill.*

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FROM PARKING TO PARKS: THE BENEFITS OF PLANTING TREES IN MELBOURNE'S THOUSANDS OF REDUNDANT CAR PARKING SPACES

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RMIT University

Abstract

City streets are often undersupplied with trees and green space. However, parking is abundant - both on streets, and in nearby buildings. With a number of trends and policies encouraging alternatives to driving, the time may be ripe for a conversion of redundant parking space to green space.

In this presentation of forthcoming research, we demonstrate how consolidation of parking into off-street garages can free up hectares of space on city streets for urban greenery. We also model the benefits in terms of tree canopy, stormwater treatment and ecological connectivity.

Overview

The City of Melbourne has a canopy cover target of 40%, formulated primarily to address the urban heat island effect. However, finding space for tree planting is challenging in highly urbanised areas, so it is important to seek opportunities for reallocation of land to tree planting. A discussion paper recently prepared as part of the city's transport plan shines a light on the extent of space allocated to parking.

Transport Strategy Discussion Paper – Car Parking

This discussion paper shows that the city has ~23,000 on-street car parking spaces. At the same time, there are almost 200,000 off-street parking spaces, and there is evidence to indicate that a significant portion of of this off-street parking is vacant. For example, residential parking spaces outnumber vehicles owned in the city by 40%. This suggests considerable redundancy; there is real potential for parking to be consolidated to free up space on city streets.

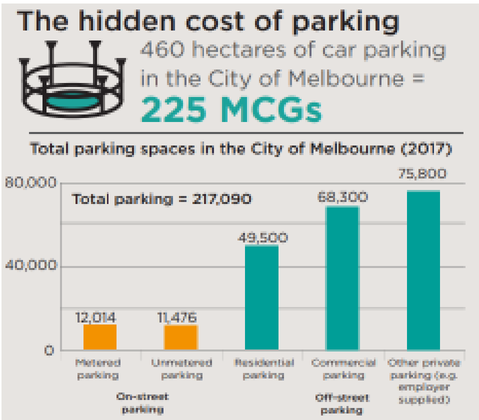

Figure 4 - Parking in Melbourne - an excerpt from a discussion paper prepared for the city's transport strategy.

On top of this abundance of off-street parking, many trends will reduce our need for parking. The rise of working from home, the construction of bike lines in many cities, the increasing availability of e-mobility and car-share, and the forthcoming emergence of autonomous vehicles all challenge the current transport paradigm.

In forthcoming research, we demonstrate that thousands of existing on-street parking spaces can be consolidated into vacant parking spaces, even if these on-street spaces can only be moved a maximum of 200m (i.e. a short walk) from their existing location. We demonstrate a simple, modular design that could be used to replace redundant on-street spaces with trees, understorey and dining space. We also model these benefits in terms of canopy, and find considerable benefits (20-50ha at maturity). Considerable benefits in terms of water treatment and biodiversity connectivity are also indicated by our modelling.

SHAPING THE LIVING ARCHITECTURE OF THE STREET: UNDERSTANDING PERTH'S NATIVE VERGE GARDEN REVOLUTION

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*This paper presents research undertaken by a research team including: Natasha Pauli, Emma Ligtermoet, Clare Mouat, Cristina Estima Ramalho, Kirsten Martinus (all University of Western Australia) and Kit Prendergast (Curtin University).

Abstract

Once a marginal practice, installing native plants on residential street verges is becoming increasingly common in the city of Perth, with a number of local governments (as well as state government entities) actively promoting and incentivising the practice. However, little information is available on the benefits and challenges of transforming the street verge to a native garden, from either the residents' point of view, nor from key stakeholders with an interest in streetscape management. This paper presents selected results of social-ecological research on suburban street verges in Perth. We interviewed verge gardeners from 22 households to understand their motivations and sources of inspiration. Concurrently, we conducted plant surveys, and observations of pollinating insects in residents' verge gardens. Most verge gardeners were motivated to reduce resource use, or improve the visual appeal of the verge. We also conducted an audit of Perth LGAs' verge gardening policies, and conducted interviews with 30 stakeholders across State and local governments, horticulture and irrigation suppliers, peak bodies, environmental consultants, utility providers, developers, and champions of change. We used participatory social network mapping to understand how knowledge of the transformative practice of native verge gardening was shared. The prevalence of native verge gardening in Perth has risen dramatically in the last ten years, accompanied by changes in governance, practical knowledge and social norms. Both 'top-down' (government-led) and 'bottom-up' (community-led) initiatives have played a significant role in dissemination of verge gardening information and practices.

Introduction

The vegetation alongside city streets and road corridors plays a key role in providing habitat for wildlife and green space benefits for people. Roadside vegetation occurs within the 'road easement', 'nature strip', or 'street verge'. We will use the term 'street verge' throughout this paper, which can be defined as the area of land between the roadway and the front property boundary. These strips of land were originally conceived as fulfilling a largely utilitarian purpose, as designated space for services such as electricity, gas, water and telecommunications, and facilities such as footpaths and bus stops. Street verges can also play a key role in providing a wide range of social, economic and ecological services.

With increasing urban housing density and greater attention given to urban forests and canopy cover, the way that street verges are managed and used in Australian cities is a rapidly evolving area of policy change and community interest. To date, most existing research on urban roadside vegetation has focussed on the role of street trees. However, the lower vegetation strata are also part of the urban forest. Further, while street trees are managed by local authorities, the ground cover and lower vegetation strata are generally maintained by residents, making an interesting case study of the intersection of public and private interests in urban greening. In the city of Perth, many local government authorities now permit residents to convert street verges in front of their dwelling from 'traditional' verge treatments such as grass to low growing, native gardens, providing certain conditions are met (Figure 1). 'Verge gardens' are perceived to require less water and better reflect a local sense of place by using plants endemic to the Perth region.

In this research project, we set out to understand the socio-ecological benefits and challenges of planting native gardens on nature strips in Perth suburbs. Nature strip gardening is a form of citizen-led urban greening, involving residents planting and caring for understorey vegetation (and even trees) along the road verge.

Perth presents a particularly interesting case study for the research, due to its location in a biodiversity hotspot, and public policy initiatives to lower water consumption as a consequence of long-term declines in precipitation observed since the 1970s, which have placed pressure on water supply. Residential gardens consume a large proportion of domestic water supply. Many local governments now offer financial incentives and rebates to encourage verge conversions. Explicit social-ecological research in urban areas presents great potential for further our understanding of the impact of urban greening programs (Pauli et al. 2020).

Figure 1: Examples of street verge gardens in suburban Perth

*There is a growing trend for households in Perth to install native and waterwise gardens on nature strips. Kangaroo paws (*Anigozanthos *spp.) are a popular choice (top L), and some gardeners mix native species with exotic species (top R). In the example across the centre, the gardener has installed a raised bed for growing herbs and vegetables. Some local governments organise 'waterwise verge garden' awards (lower L). Some native verge gardeners incorporate annuals amongst local endemics for a vibrant display in spring (lower R).*

The overall aim of this research was to gather empirical data on the social and ecological values of street verge gardens in Perth, to better support decision making by local authorities and local residents. The major objectives of the research were to:

- Understand, the motivations and challenges for native verge transformations from the perspective of the residents, highlighting the potential social impacts of verge gardening activities.
- Quantify potential ecological values by sampling a selection of transformed verge gardens for plants, birds, and flower-visiting insects.
- Capture a snapshot of Local Government Authority (LGA) policies and perspectives on verge transformation with native species, as the primary stakeholder managing this land area.
- Understand the network of interactions between stakeholders, especially in terms of information sharing.

We developed recommendations for decision makers (including local authorities and local residents) to ensure that the social and ecological potential of native verge gardens can be realised, and highlight the particular challenges that are associated with this activity. Full details of the research results and recommendations are provided in Ligtermoet et al. (2021) and Pauli et al. (2021).

Methods and results

Social and ecological values of verge gardens

A key element of the research involved understanding the social and ecological values of a range of different native verge gardens, established for different lengths of time, and in different parts of metropolitan Perth. The research team approached representatives of two suburban Perth LGAs which had long-established incentive programs promoting native verge gardens (City of Subiaco representing the inner city, and City of Stirling representing middle-ring suburbs), to ask them to distribute an invitation to residents to participate in the research. A strong initial response from residents demonstrated a high level of interest in participating in this kind of research.

We interviewed verge gardeners from 22 households to understand their motivations and sources of inspiration. Verge gardeners were selected to cover a range of socio-demographic variables, as well as a range of verge garden sizes and ages. Interview questions centred on the drivers, challenges and opportunities encountered during verge gardening. Concurrently, we conducted plant surveys, and observations of pollinating insects in residents' verge gardens. Pollinator observations were conducted three times over the period October 2019-March 2020, during the period of maximum activity for native bees. Pollinator surveys identified the presence of at least eight species of native bees visiting verge gardens.

In terms of initial motivations for undertaking verge transformations, the most common reasons reflected practical motivations to reduce time, expense, water use and maintenance. Figure 2 highlights the major reasons given for converting verges to native gardens. There was limited overlap between residents nominating wanting to reduce water use, and residents wanting to improve the visual appeal of the verge. This suggests that aesthetic concerns and norms are a key driving factor for verge conversions, which has potentially been overlooked in research to date. While some respondents had an initial interest in native plants, most people interviewed had limited initial knowledge, and learnt more about native species and ecology through the process of verge gardening. This indicates that limited knowledge of native plants is *not* a barrier for residents wishing to commence a verge garden.

Households gain a variety of benefits from verge gardening, including personal satisfaction, shade and cooling, privacy from the street (if desired), connection to nature, and social interaction while out on the verge. The benefits vary widely by household, depending on individual preferences. A neighbourhood streetscape and network approach can help verge gardens act as connectors between neighbours, as well as appropriately develop habitat for small animals and invertebrates.

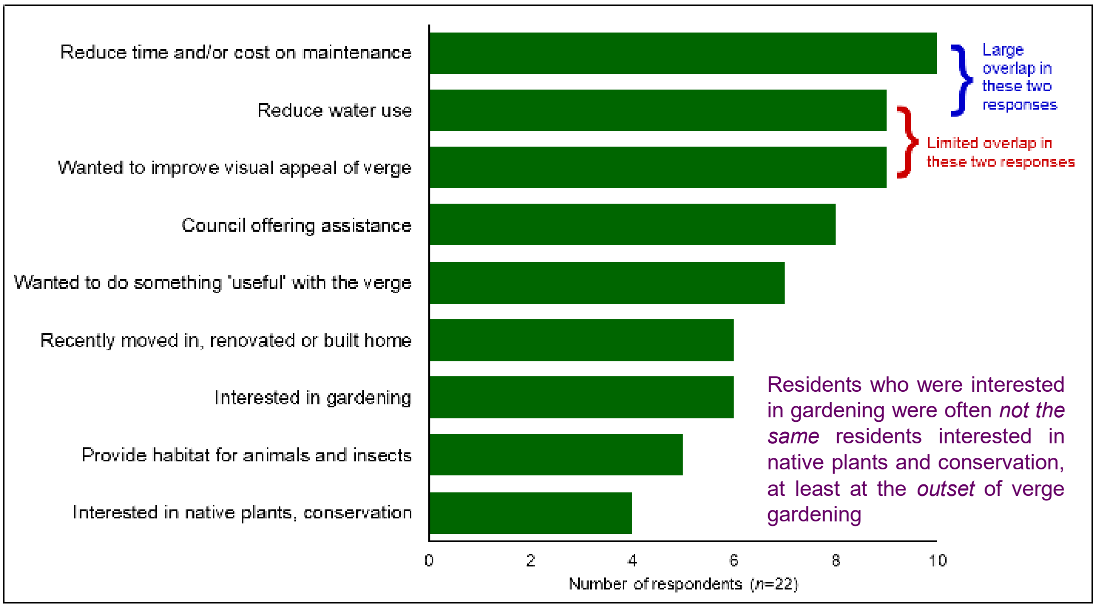

Figure 2: Initial impetus for verge transformation

Note that many respondents provided more than one reason for their initial decision to transform their verge. Excluded from the graphic are reasons with three or fewer responses. Responses were classified based on respondents' answers to interview questions.

Plant surveys identified at least 265 distinct species from the 22 verge gardens. The geographic origins of species identified from verge gardens are shown in Figure 3. Around 41% of the species planted occur naturally on in the Perth subregion of the Swan Coastal Plain IBRA[1] region, and a further 28% of species originated elsewhere in Western Australia. In terms of choosing particular species, many residents wanted to have either Australian native plants, or endemic Swan Coastal Plain plants. The motivations behind this were multiple: some residents wanted to choose species that were likely to survive, being from the local area, whereas others wanted to provide habitat for local species in a miniature replica of remnant vegetation. The most commonly planted species closely reflect the species that were pre-selected for distribution to residents by local government authorities (about half of the respondents had received assistance from their local councils for the verge garden transformation, often in the form of free or subsidised plants). This close link demonstrates that verge species composition can be heavily influenced by local authorities.

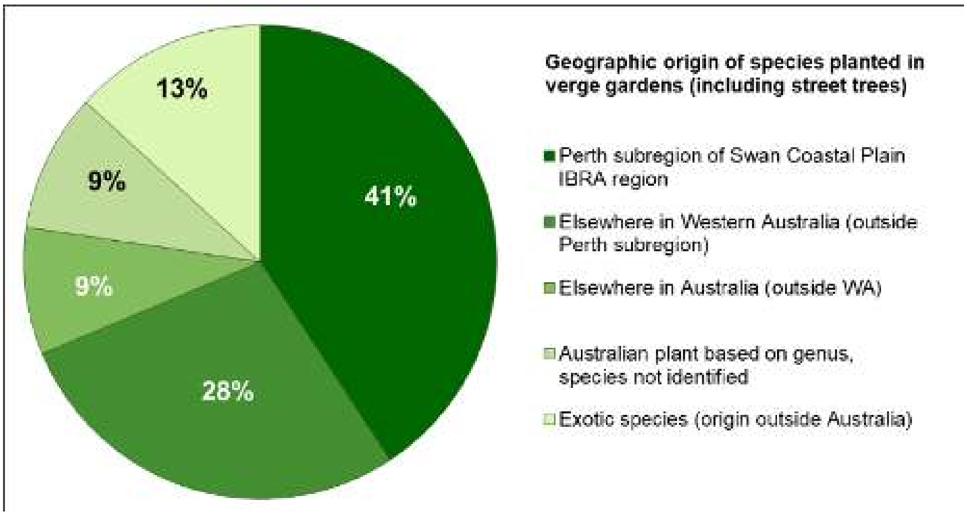

Figure 3: Location of origin for species deliberately planted in native verge gardens

[1] Interim Biogeographic Regionalisation of Australia

Based on interviews with residents, we developed a preliminary 'typology' of verge gardeners, which can be related to policy decisions (Figure 4). 'Early Adopters' are motivated by a combination of a sense of environmental responsibility and interest in ecology and conservation, and rarely access incentive programs, but could act as sources of inspiration. 'On The Fence' residents had toyed with the idea, but made the final decision to start because of incentive programmes. Residents in the 'About Time' category timed verge transformations with events such as retirement, moving, building and renovating.

Left - Figure 4: A typology of verge gardeners.
The categories at right are not exclusive – some residents would fit into multiple categories.

Verge garden policy audit

The research team undertook an audit of publicly available verge garden and urban forest policies for 31 LGAs in the Perth region. As of January 2021, all but two LGAs had a publicly available verge policy online, and all but one permit native verge gardens. Twenty of the 31 LGAs had Urban Forestry or Greening plans (including two in draft status). Of the 31 LGAs, only nine LGAs currently require residents to obtain permission to install a native verge, while 21 allow residents to install native verge gardens without special permission, providing that the LGA guidelines are followed. Plant height restrictions are variable, ranging between 50 cm to 75 cm, with some LGAs simply that plant height allows for clear lines of sight at all times. The full audit of LGA verge garden policies can be found on pages 21-24 of Ligtermoet et al. (2021) (publicly available report).

There has been a rapid increase in the development of verge garden policies in Perth over the last decade, and even in the last few years. A small number of LGAs have long-standing (i.e. 10^{+} years) policies on native verge gardens, while most have developed guidelines more recently. The increased visibility of verge garden policies may have been driven by a range of factors specific to the Perth context, including active community groups and promotion by influential actors at the state and local government level. Among these drivers may be that LGAs must have a waterwise verge policy in order to be certified as a 'Waterwise' Council by the state water utility, the Water Corporation (a government trading entity). An integral component of the research project was to understand how different stakeholders have interacted to disseminate knowledge on verge gardening in Perth, in terms of knowledge of both policies and guidance, and the technical knowledge of how to undertake verge conversions.

Mapping verge garden knowledge networks

The research team conducted interviews with 30 stakeholders across a broad range of categories, including State and local governments, horticulture and irrigation suppliers, peak bodies, environmental consultants, utility providers, developers, and champions of change. We used participatory social network mapping to understand how knowledge of the transformative practice of native verge gardening was shared. During interviews, each respondent was asked to draw a social network map of how they interacted with key stakeholders to share information, resources, labour and finances related to native verge gardening. The exercise resulted in 268 named entities or individuals within the collective stakeholder network, and almost 1000 separate directional flows of resources among entities in the network.

Network analysis using a measure of 'betweenness centrality' (an indicator of the degree to which an individual entity forms a link between other entities – and can therefore act as an important broker of information) uncovered a number of similar 'communities' in terms of the way that they share information. The different entities within each 'community' cover a range of different stakeholder types, which indicates that the knowledge network for sharing information and resources on verge gardens is diverse, with interaction and discussions across traditional 'siloes', and direct flows of information between community champions and elected officials in positions of influence.

The full network, coded according to the different communities, is shown in Figure 5. A more detailed breakdown of the stakeholders represented in the two central communities of 'Promoters' and 'Enablers' is presented in Figure 6, highlighting the close relationship that enables change to occur in streetscape vegetation policy and practice.

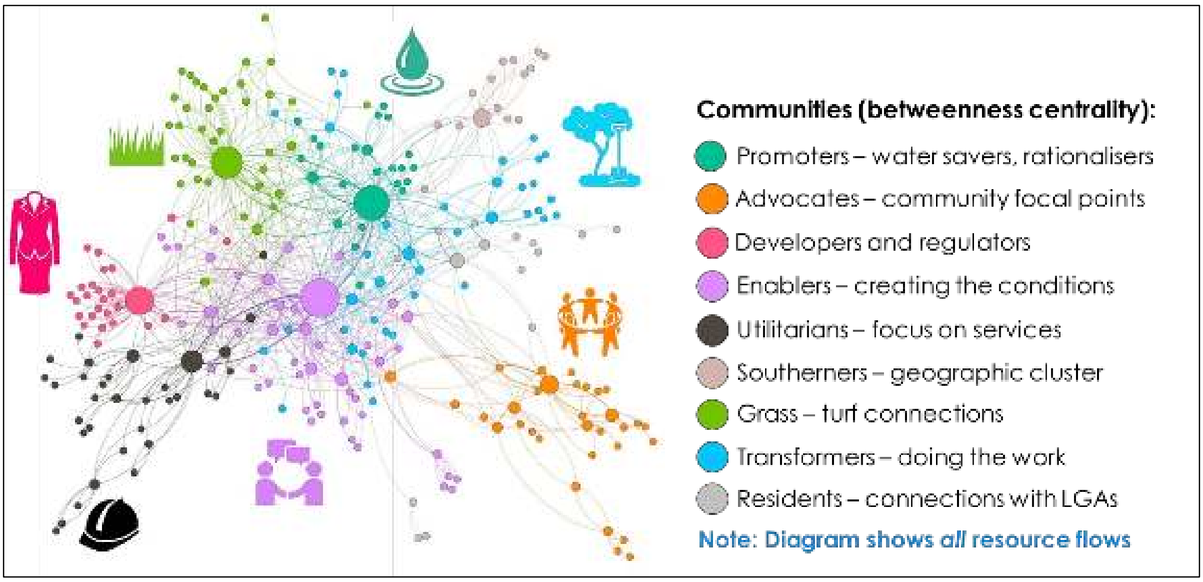

Figure 5: Graphical representation of social network analysis based on 'betweenness centrality' metric.

Social network analysis produced by Kirsten Martinus. Communities named based on commonalities in mode of operation, as defined by the author.

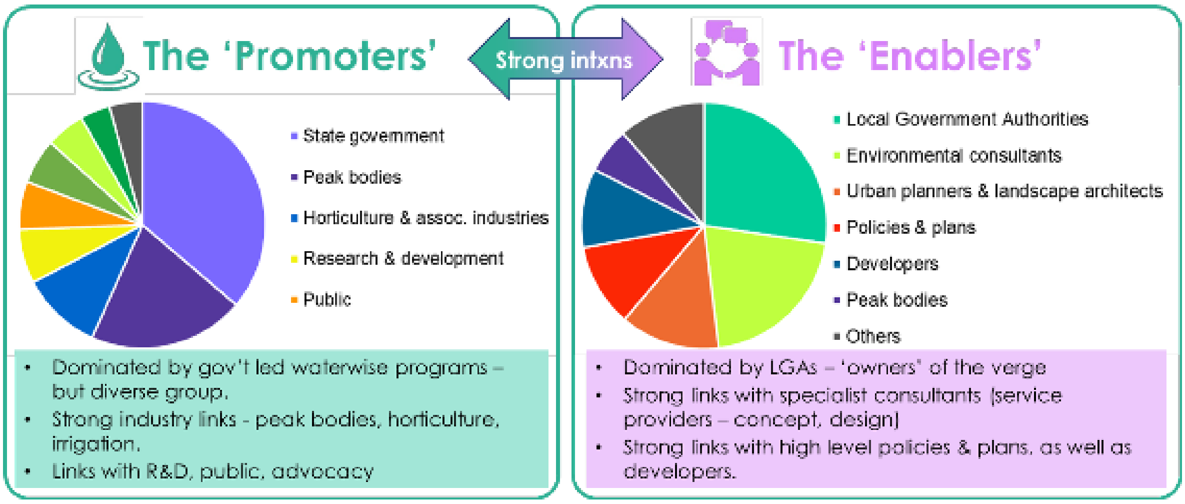

Figure 6: Breakdown of the stakeholders involved in each of two influential 'communities' in verge gardening.

'Promoters' provide the impetus for policy change to occur, advocating for native vegetation on streetscapes, and often providing incentives and knowledge that can aid 'Enablers'. 'Enablers' respond to 'Promoters' by enacting the changes at a local level that need to occur for uptake of new/different streetscape vegetation policies. Each community is comprised of a particular number of specific entities, as identified in social network analysis. The pie chart shows the percentage of specific entities that have a primary affiliation with particular stakeholder types. For example, under 'Promoters', approximately one-third of all the entities from this community are State government stakeholders, and around one-fifth are from different Peak Bodies.

Key findings

This three-year program of research uncovered a diverse range of key findings relevant to the role of native verge gardens in urban greening. An expanded list of key findings are provided in Ligtermoet et al. (2021) and Pauli et al. (2021). From the overview results presented here, key findings include:

- Native verge gardens can showcase and normalize the use of local native plants in landscaping, as well as provide some additional habitat and foraging space for native fauna (including invertebrates). While individual front verge gardens are small patches, collectively they can add up to larger areas, particularly if linked with vegetated corridors in public green spaces and along arterial roads. Research in other places has found that verge gardening is 'contagious' along streets – as verge gardens appear, more and more residents are inclined to also take up the practice.
- Native verge gardens have shifted from a marginal practice to one that is sanctioned by most local government authorities in the city of Perth. Social norms have also shifted, with increasing uptake of verge conversion incentive programs by residents. The appearance of specialist verge landscaping firms and commercially-available nursery ranges of plants promoted as 'verge-suitable' highlights the increasing demand for native verge gardens.
- Residents who had taken part in incentive and rebate programs delivered by local governments were generally appreciative and espoused positive views of "the council", often to their neighbours. Residents who had not taken part in incentive programs were often more wary or circumspect in their views as to "the council's" approach and attitude towards verge transformations, sometimes being concerned about potential punishment or lack of acceptance of residents' plans or ideas.
- Verge gardeners may be primarily interested in *either* saving water *or* in creating a more visually appealing street frontage. Those who are less interested in water conservation may still choose plants that require regular irrigation, or might overwater plants that are actually waterwise. To achieve both water conservation and aesthetic improvement, practical information and visual examples of how to achieve a beautiful, waterwise garden are required.
- Workshops, local government websites, booklets and 'how-to' videos are valuable sources of information for verge gardeners. Street verges present challenges that set them apart from other domestic garden zones, including poor soil, depleted nutrients, persistent weeds, higher temperatures and sometimes full shade. Many verge gardeners are novices with native plants, and require specific information on soil preparation, local endemic species and where to buy them, and watering needs.
- The prevalence of native verge gardening has risen dramatically in the last ten years, accompanied by changes in governance, practical knowledge and social norms. Stakeholder and social network analysis revealed a surprising diversity of stakeholders and the important role of both 'top-down' (government-led) and 'bottom-up' (community-led) initiatives in the dissemination of practical knowledge.

Our research provides a fascinating road map of how a once marginal social-ecological practice can become mainstream.

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We would like to acknowledge that this research took place on Whadjuk Noongar Boodja (Country), metropolitan region of Perth. We respectfully acknowledge the sovereignty of all of Australia's first peoples, their ancestors, and Elders, past, present and emerging and that their lands and waters of Australia have never been ceded.

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THE TREE PROJECTS

Steve Pearce and Dr Jennifer Sanger

The Tree Projects is an environmental outreach organisation that aims to educate people about the importance and beauty of trees. We do this by creating unique and engaging photos and videos about forests and tall trees. We also help to promote tree based tourism and encourage people to engage with forests via tree climbing. The organisation is run by Steve Pearce, a wilderness photographer and film maker, and his wife, Dr Jennifer Sanger, who is a forest ecologist.

One of our signature outputs are our 'tree portraits'. For the last six years we have captured stunning photographic portraits of impressive rainforest trees in New Zealand, Tasmania, Taiwan, Western Australia and the USA. These Tree Portraits are a complete, distortion-free image of an entire, extremely tall tree. When you stand at the base of a large tree and look up, the top of the tree is often obscured by the lower branches, making it extremely difficult to get a sense of the full scale of the tree. Our Tree Portraits allow people to appreciate, for the first time, a tree's true size and beauty.

We also create informative videos and documentaries to help educate people about the importance of trees. This year we produced a film called the Big Tree Hunters which followed the journey of five young Tasmanians as they ventured into the forest to discover Tasmania's remaining big trees. It also highlights how a lot of Tasmania's giant trees are still being logged, and what people are doing to help conserve these beautiful trees. Steve was also the recipient of Dahl Fellowship and produced the EUC2020 videos which were aimed at educating teenagers about Eucalypts.

The Tree Projects also encourages people to go out and discover the forests for themselves. We produced the Giant Tree Register in our home state of Tasmania which shows 200 of Tasmania's tallest trees. We have collated all of our information gathered from LiDAR and many other different sources. Our intention is to inspire a new generation of big tree hunters dedicated to exploring Tasmania's forests. We do this so that more of Tasmania's giant trees can be discovered, documented and protected. We believe that tree based tourism is a much more sustainable and profitable industry for regional communities than logging.

As tree climbers, we also found that getting people to the trees is a great way to engage people in trees and forests. We started the Hobart Recreational Tree Club where we facilitate people in tree climbing. The club is open to any adult who is interested and is completely free. Once participants are experienced enough, they graduate from park trees and we take them out to climb an 80m tall tree in the forest. It is an incredible experience for people to climb up into these giant trees. We have had over 30 people climb with us through the club.

https://www.thetreeprojects.com/