VALUING THE URBAN FOREST OF CAMBRIDGE

TECHNICAL REPORT

Cambridge City Council

Treeco2nomics

CAMBRIDGE CITY COUNCIL

i-Tree

Forest Research

This report is dedicated to the memory of

Olivia Norfolk

Lecturer at Anglia Ruskin University

A tree has been planted in her memory.

Acknowledgements

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Funders

This project was funded as part of the Interreg Nature Smart Smart Cities 2 Seas project.

Supporters:

Cambridge City Council, Anglia Ruskin University,

With Thanks

We wish to thank all landowners and members of the public who granted access to their properties for the collection of the field data; and to all householders who volunteered to survey sample plots that fell in their properties during Covid-19 lockdown, without which there would be no study.

This project was kindly supported by Anglia Ruskin University who provided student surveyor and staff supervision.

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Treeconomics is a social enterprise, whose mission is to highlight the benefits of trees. Treeconomics works with businesses, communities, research organisations and public bodies to achieve this.

Forest Research is Great Britain's principal organisation for forestry and tree related research. Forest Research aims to support and enhance forestry and its role in sustainable development by providing innovative, high quality scientific research, technical support and consultancy services.

i-Tree is a state-of-the-art, peer-reviewed software suite from the USDA Forest Service that provides urban and community forestry analysis and benefits assessment tools, including i-Tree Eco. The Forest Service, Davey Tree Expert Company, National Arbor Day Foundation, Society of Municipal Arborists, International Society of Arboriculture, and Casey Trees have entered into a cooperative partnership to further develop, disseminate and provide technical support for the suite.

This report was produced for Cambridge City Council, as part of the Interred Nature Smart Cities 2 Seas project.

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European Regional Development Fund

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Key Definitions

Urban forest: The trees in and around our urban areas (together with woodlands, shrubs, hedges, open grass, green space and wetland) are collectively known as the 'urban forest'.

Ecosystem services: refers to the benefits which trees provide to the surrounding environment and people. This includes a range of benefits, from urban cooling to amenity value. In this report, the ecosystem services measured are carbon storage and sequestration, pollution removal and avoided surface run-off.

i-Tree Eco: a software application which quantifies the structure and environmental effects of urban trees and calculates their value to society. It was developed as the urban forest effects (UFORE) model in the 1990's to assess impacts of trees on air quality and has since become the most complete tool available for analysing the urban forest. Eco is widely used to discover, manage, make decisions on and develop strategies concerning trees in urban landscapes.

Links

Further details on i-Tree Eco and the full range of i-Tree tools for urban forest assessment can be found at: www.itreetools.org. The website also includes many of the reports generated by i-Tree Eco studies from around the world.

For further details on i-Tree Eco in the UK, on-going i-Tree Eco model developments, training workshops, or to download reports on previous UK i-Tree Eco studies visit www.treeconomics.co.uk or www.forestresearch.gov.uk/research/i-tree-eco.

Executive Summary

Trees in and around our urban areas (together with woodlands, shrubs, hedges, open grass, green space and wetland) are collectively known as the 'urban forest'. This urban forest improves our air through removing pollutants, protects watercourses, saves energy, and improves economic sustainability. There are also many benefits which cannot currently be quantified associated with being in close proximity to trees some of these include: improving physical health and mental wellbeing, providing shade and reducing the heat island effect, improving biodiversity through food and habitat provision, and more. These benefits are also known as ecosystem services (referred to as ES throughout).

This report will quantify and value a number of ES and capture a snapshot of Cambridge's urban forest at the present time. This report includes both public and private land, thereby giving a full picture of the green landscape of Cambridge, not just the parts owned and managed by the Council. It does not consider how the urban forest has or might change over time, or the reasons for this change. Its purpose is to provide a means to make informed decisions to ensure the urban forest is healthy and resilient, and how it should change in the future.

As part of this study it is estimated that there are 212,000 trees in Cambridge with a total leaf area of 3,470 ha. The most common tree genera are *Crataegus* with 26,600 trees, *Prunus* with 23,600 trees, and *Acer* with 22,600 trees.

In terms of ecosystem service provision, these trees have the potential to trap and remove 22 tonnes of air pollution annually, including sulphur dioxide (SO_2), particulate matter (PM2.5) and nitrogen dioxide (NO_2). They reduce surface runoff by over 97,600 m^3 per year. This volume is equivalent to 39 Olympic swimming pools of surface runoff being averted every single year, and is worth an estimated £153,000 in avoided water treatment costs. These trees also store around 88,000 tonnes of carbon and sequester more than 2,040 tonnes of carbon per annum with associated values of £22,600,000 and £524,000 respectively. For reference, the average newly registered car in the UK produces 34.3g carbon per km. Carbon sequestration across all sites therefore corresponds to around 5,950,000 'new' vehicle km per year, which is equivalent to 1,140 people driving a car every year (Department for Transport, 2019).

The Trees are estimated to be worth £172 million in replacement cost, and £1.03 billion in amenity value to the residents and visitors of Cambridge. Trees also confer many other benefits such as removing carbon monoxide and ozone pollution, habitat provision, soil conservation, and noise reduction which currently cannot be valued.

Highlights

Structure and Composition				
Number of Trees (estimate)	212,000			
Average Tree Density (estimate of trees per hectare)	52			
Tree Cover	13.3%			
Shrub Cover	6.8%			
Total Canopy Cover (Tree + Shrub Cover)	20.1%			
Number of Species Surveyed	105			
Proportion of Trees in Good or Excellent Condition	36.6%			
Replacement Cost	£172,000,000			
Amenity Value (CAVAT)	£1,030,000,000			
Most Common Tree Genera	*Crataegus* 12.5%	*Prunus* 11.1%	*Acer* 10.6%	
Most Common Tree Species	*Crataegus monogyna* 11.1	*Acer campestre* 6.6%	*Ulmus procera* 4.5%	
Proportion of Trees by Diameter at Breast Height (DBH)	0-15 cm 26.4%	15-45 cm 49.5%	45-75 cm 20.0%	75+ cm 4.2%

Ecosystem Services		
Carbon Storage (whole value)	88,000 tonnes	£22,500,000
Carbon Sequestration (annual)	2,040 tonnes	£524,000
Pollution Removal (annual)	22.2 tonnes	£990,000
Avoided Runoff (annual)	97,600 m³	£153,000
Total Annual Benefits		£1,670,000

Table 1: Headline figures.

Use of this report

This report can be used to:

- Answer questions such as: How many trees do we have in Cambridge? Which species do we already have in Cambridge? Do we have an even distribution of young trees to older trees? What could Cambridge focus on when planting new trees in future?
- Understand the quantity and value of benefits provided by the urban forest of Cambridge to the environment and to local communities
- Make decisions about the urban forest, such as protecting existing mature trees, or those vulnerable to pests and diseases.

This report can be used by:

- Urban planning departments
- Planning, environmental and sustainability policy writers
- Volunteers or teams working to protect and manage local trees
- Individuals planning to plant new trees
- Local nature partnerships.

1.0 Introduction

Built around the banks of the River Cam, to the North-East of London, Cambridge covers an area of 4,070 hectares with 744 hectares of designated Protected Open Spaces (POS). Cambridge has a tree canopy cover of 17.0%, exceeding the average for England of 16.0% (Forest Research, 2021). Cambridge's target to increase this to 19.0% will require over 800,000 m^2 of new tree cover. This target aligns closely with literature recommendations reporting that 20.0% canopy cover is a good aspiration (Doick *et al.*, 2017).

The green spaces and canopy cover of Cambridge are under threat from residential development required to accommodate Cambridge's growing population (Cambridge City Council, 2003). To retain and maintain their leafy heritage, there is a well-understood need to protect and manage established trees, whilst continuing to plant the right tree in the right place. The 2011 census reported that the population of Cambridge was 124,000, which was an increase from the previous census in 2001. Alongside the increasing population, the number of households increased by 9.5% (Cambridge City Council, 2021a). The population is predicted to reach around 150,000 by 2031. The city has an additional large student population (est. 29,000) from the University of Cambridge and Anglia Ruskin University.

New housing development of around 7,000 homes is ongoing. Plans for the future include a focus on developing and promoting sustainable transport options. The average number of people using sustainable modes of transport is higher in Cambridge than in most other areas in the UK (15.0%) with 33.0% of residents commuting to work by bicycle. Inspiration for new buildings will draw upon the historic core, and natural features such as the River Cam.

This Cambridge i-Tree Eco project aims to:

1. Illustrate the structure of Cambridge's urban forest, including the genus composition, diversity, and tree condition.
2. Calculate the ES values provided by Cambridge's urban forest and rank the importance of different trees in terms of ES provision using the i-Tree Eco software suite.
3. Promote Cambridge's urban forest to all, and emphasise the benefits it provides.
4. Engage and train volunteers in the data collection field work.
5. Establish values that are a precursor to proper asset and risk management.
6. Conduct a risk analysis of the susceptibility of Cambridge's urban forest to pests and diseases.

2.0 Policy Context

In the UK, the law, national and local policy serve different purposes and have distinct characteristics. Legislation is a set of rules that are enforceable by the state, they are binding and mandatory. National and local policies are a set of principles to guide actions to achieve a goal. Local policies should align with national policy that are set by the Government, and both should comply with existing laws.

Statutory duties and responsibility – Local Planning Authority

Cambridge City's Council's Tree Team currently discharge the local authority's duties and responsibilities under the Town & Country Planning Act, Local Government (Miscellaneous Provisions) Act allowing for a more holistic approach to be taken urban forest management by the Tree Team. Cambridgeshire County Council are responsible for the Highways Act and the Greater Cambridge Shared Planning Service, Part 6 Environment Act.

Town & Country Planning Act

The Local Planning Authority has a statutory duty to:

- Include appropriate provision of the preservation and planting of trees in relation to planning consents (section 197 Town and Country Planning Act 1990[1](TCPA)). Implicit within the preservation of trees in relation to applications for development are all the activities of site and proposal analysis, tree selection, protection and care
- Make tree preservation orders in the interests of amenity (section 198 TCPA[1])
- Process applications for works to trees subject to an order (section 198 (3a)[1]) and to respond to notifications of intent to implement tree works within a Conservation Area (section 211 (3 a and b) TCPA[1])

Statutory Responsibilities – Other

Section 23 of the Local Government (Miscellaneous Provisions) Act 1976[2] confers a power on local authorities to make safe dangerous structures. With the result that a private owner can serve notice on the authority requiring action to remove or make safe dangerous trees.

The Highways Act 1980 has provisions for the planting and maintenance of trees on highway land and confers a power under section 154[3] to enforce action or eventually take action to prevent highway safety from trees on adjacent land, regardless of ownership. The Act, under section 96[3]

[1] Town and Country Planning Act 1990 (legislation.gov.uk)

[2] Local Government (Miscellaneous Provisions) Act 1976 (legislation.gov.uk)

[3] Highways Act 1980 (legislation.gov.uk)

confers a liability on the council for trees planted to highway land which increase the population. Under Section 96A[3] local highway authorities have a duty to consult before felling street trees. In addition, local authorities, as with all individuals and organisations, have a duty of care in relation to their activities and ownerships. Trees in council care, either by ownership or agreement, need to be actively managed to avoid negligence claims.

The above statutory responsibilities benefit from Government and industry-based guidance in the form of Planning practice guidance[4], British Standards and practice notes.

Biodiversity Net Gain

Part 6, Environment Act 2021, Clause 102[5]
Biodiversity net gain is a way to contribute to the recovery of nature while developing land. It is making sure the habitat for wildlife is in a better state than it was before development.

National Policy

A Green Future: Our 25 Year Plan to Improve the Environment (2018)[6]

The government's environment plan sets out its goals for improving the environment within a generation and leaving it in a better state.
Summary of policies include:
3. Greening our towns and cities
    i. Creating more green infrastructure
    ii. Planting more trees in and around our towns and cities

Under the plan the various funds have been created to facilitate tree planting including the following which are still open:

Local Authority Treescape Fund[7](LATF)

The LATF support replacement planting. The council has three schemes running under this fund as of 2024.

Urban Tree Challenge Fund[8] (UTCF)

The UTCF supports the planting of trees in deprived areas. The council has three schemes running under this fund as of 2024.

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[4] Planning practice guidance - GOV.UK (www.gov.uk)

[5] Environment Act 2021 (legislation.gov.uk)

[6] 25-year-environment-plan.pdf (publishing.service.gov.uk)

[7] Local Authority Treescapes Fund - GOV.UK (www.gov.uk)

[8]Urban Tree Challenge Fund - GOV.UK (www.gov.uk)

Environmental Improvement Plan (2023)

The Environment Act 2021 requires the 25 Year Plan to be refreshed every five years. This document is the first such review and it builds on the 25 Year Plan's vision.

- *Increase tree canopy and woodland cover to 16.5% of total land area by 2050. Page 35*
- *Increasing tree planting on public land and support local authorities to plant more trees. Page47*

England Trees Action Plan 2021-2024[9]

The government's long-term vision for boosting tree planting.
Well sited tree planting, with appropriate management can make places where people live and work more climate resilient, healthy and attractive (Page 7).

Trees outside of woodlands are among the most valuable to society. People place great value on trees and green spaces in their local communities, which also provide connections in our fragmented treescapes and vital habitat for threatened biodiversity. Yet they often slip through the gaps between funding mechanisms, contributing to their long term neglect and decline. We need to reclaim our neglected public land, create tree-based community green spaces and encourage new trees in non-woodland settings, for people and nature (Page 26).

Planning policy

Cambridge City's planning service is managed by the Greater Cambridge Shared Planning Service[10] (GCSPS). This is a shared service for South Cambridgeshire District Council and Cambridge City Council. Cambridge City's Council's Tree Team provide an arboricultural consultancy service to the GCSPS's Policy and Delivery Teams allowing for a more holistic urban forest management approach to be taken by the Tree Team.

National Planning Policy Framework[11] (NPPF)

The National Planning Policy Framework sets out the government's planning policies for England and how these should be applied.

The NPPF (2023) Clause 136:
Trees make an important contribution to the character and quality of urban environments and can also help mitigate and adapt to climate change. Planning policies and decisions should ensure that new streets are tree-lined, that opportunities are taken to incorporate trees elsewhere in

[9] The England Trees Action Plan (publishing.service.gov.uk)

[10] About us (greatercambridgeplanning.org)

[11]National Planning Policy Framework - Guidance - GOV.UK (www.gov.uk)

developments (such as parks and community orchards), that appropriate measures are in place to secure the long-term maintenance of newly planted trees, and that existing trees are retained wherever possible. Applicants and local planning authorities should work with highways officers and tree officers to ensure that the right trees are planted in the right places, and solutions are found that are compatible with highways standards and the needs of different users.

Cambridge Local Plan 2018[12]

The Cambridge Local Plan forms part of the development plan for Cambridge. It sets out the vision, policies and proposals for the future development and land use in Cambridge to 2031. It is the main consideration in the determination of planning applications. It contains numerous policies that relate to trees, and is linked to many service specific strategies.

An essential part of the character of the city stems from the spaces and grounds around buildings and the important role of trees and other landscape features. Page 4

Strategic objective 6
Protect and enhance the landscape setting of the city, which comprises the Cambridge Green Belt, the green corridors penetrating the urban area, the established network of multifunctional green spaces, and tree canopy cover in the city. Page10

Cambridge City Council

The corporate plan sets the direct of travel under which all other council plans follow. Tree care and planting are involved in the delivery of all of the council's four key priorities. Specific policies are to be found in the Tree Strategy under which this i-Tree Eco study was procured, and the importance of tree benefits reflected in the aim and objectives of numerous other council strategies.

Corporate plan 2022-27[13]

Cambridge City Council's four key priorities for 2022 to 2027 are:

- *Leading Cambridge's response to the climate and biodiversity emergencies and creating a net zero council by 2030*
- *Tackling poverty and inequality and helping people in the greatest need*
- *Building a new generation of council and affordable homes and reducing homelessness*
- *Modernising the council to lead a greener city that is fair for all*

[12] Cambridge Local Plan

[13] Corporate plan 2022-27: our priorities for Cambridge - Cambridge City Council

Citywide tree strategy 2016-2026[14]

This strategy sets out Cambridge City Council's policies for managing the city's trees to maximise their benefits. Its vision is:

"To manage our city's trees so as to maximise the benefits they offer, whilst ensuring that the trees we leave for future generations, and the character they bring to our city, are better than those we have inherited."

It states:

- *City of Cambridge's tree population contributes greatly to the city's character and is integral to providing cleaner air, filtered storm water and lower city temperatures*
- *Trees, shrubs and other plants create an important habitat for birds and insects and make the city beautiful*
- *Streets, parks and gardens filled with trees can also have psychological benefits in reducing stress and providing spaces for relaxation and contact with nature*
- *The council will work to ensure a resilient tree population that respects Cambridge's unique character, responds to climate change and urban expansion and underpins the health, liveability and well-being of the city and its inhabitants by taking an integrated approach to the management of the city's trees, regardless of ownership*
- *This integrated management approach to achieving the council's long-term vision has the following aims:*
  - *To sustainably manage the council's own trees and those it manages by agreement*
  - *To foster a resilient tree population that responds to the impacts of climate change and urban expansion*
  - *To raise awareness of trees being a vital community asset, through promoting continued research, through education via the provision of advice and through partnership working*
  - *To make efficient and strategic use of the council's regulatory powers for the protection of trees of current and future value*

The strategy takes an urban-forest approach to the protection of tree canopy utilising a variety of management tools in a single unified team to influence both the public and private realms:

I. Tree preservation orders
II. Planning conditions
III. Asset management
IV. Engagement
V. Funding and partnerships
VI. Research and information
VII. Advice and safety

[14] https://www.cambridge.gov.uk/tree-strategy

Biodiversity Strategy 2022-2030[15]

The council's nature conservation strategy helps prepare for a predicted net gain in biodiversity over the next two decades. It covers the extent and quality of priority habitats and populations of priority species.

Cambridge is a 'green' city. Beyond the formal greenspaces such as designated areas and parks, there are also numerous informal greenspaces, including community gardens and orchards, private gardens as well as college grounds, street trees and increasingly, green roofs. Canopy cover from trees in the city is estimated to average 17% across the wards, and these trees alone make a significant contribution to the biodiversity resource in Cambridge. Page 19

Climate change strategy 2021-2026[16]

- *Objective 6. Supporting Council services, residents and businesses to adapt to the impacts of climate change.*
  - *Increasing the number of trees in Cambridge through tree planting activities, including a major tree canopy project. (page 8)*
- *Opportunities. While climate change presents very significant challenges, there are a number of opportunities to respond with greater impact created by recent developments:*
  - *Building on increased public awareness of the effects of climate change and the need to adapt to them. For example, in the context of both the climate emergency and Covid-19, the health and wellbeing benefits of trees, green space and other green infrastructure received high levels of public interest and support. (page 10)*
- *OBJECTIVE 5. Promoting sustainable food.*
  - *Using guidance in the Sustainable Design and Construction Supplementary Planning Document (SPD) to encourage developers to incorporate food growing in new housing and non-residential development (e.g. providing fruit trees, roof top gardens and growing space as part of landscape design). p48*
- *OBJECTIVE 6. Supporting Council services, residents and businesses to adapt to the impacts of climate change.*
  - *Council land, residents, businesses and institutions – increasing tree canopy cover. As well as helping to absorb carbon emissions, trees can help reduce climate change impacts, such as overheating (by providing shade and cooling and reducing the Urban Heat Island effect) and flooding (by slowing surface water run-off). The Council is helping to enhance tree canopy cover and other "green infrastructure" in Cambridge by:*

[15] https://www.cambridge.gov.uk/biodiversity

[16] Climate change strategy - Cambridge City Council

- *Implementing the Council's tree strategy, which focuses on managing over 30,000 trees on Council land sustainably and protecting and enhancing the 210,000 trees that exist on land owned by universities, hospitals, institutions, businesses, individual householders and other landowners. The strategy sets out 56 actions relating to the protection, management and enhancement of the urban forest*
- *Increasing the number of trees in Cambridge through tree planting activities. In 2019/20 the Council planted 500 trees and gave away a further 350 trees to residents as part of the 'Free Trees for Babies' scheme.*
- *Launching a major Cambridge Canopy Project which aims to significantly increase the tree canopy in Cambridge from 17% to 19% of the area of the city (the average canopy cover in England is 16%) (Page 53).*

Climate strategy Action Plan: 2021-2026[17]

- *Action 5.7*
  - *Using guidance in the Sustainable Design and Construction Supplementary Planning Document (SPD) to encourage developers to incorporate food growing in new housing and non-residential development (e.g. providing fruit trees, roof top gardens and growing space as part of landscape design)*
- *Action 6.6*
  - *Increasing the tree canopy cover through tree planting and protection on public and private land, and using parks, open spaces and other green infrastructure in the city to help regulate temperatures.*

Cambridgeshire County Council

The adopted streets and roads form around 9% of the land area of the city andcontribute a similar proportion of the tree canopy. Because of their public accessibility and benefits to highway users and managers they are an extremely important asset. Highway trees are owned by Cambridgeshire County Council but have been managed by the City Council for many decades. Since 1996 recorded tree numbers growing on highway land have doubled. The City Council's Tree Strategy is in line with County's vision and ambitions for tree cover.

[17] https://www.cambridge.gov.uk/climate-change-strategy

The County Council's Tree & Woodland Strategy (under development)[18]

Its vision for trees is to:

- *6. Manage our trees sustainably and carefully to ensure they are located and looked after in ways that maximise their benefits to the council, and;*
- *7. Enhance and expand our own trees and woodlands to ensure the benefits can be realised and shared.*

Interim corporate tree & woodlands strategy[19]

- *Our vision is to expand, protect and improve our trees, woodlands and hedgerows and how they can connect people to nature, support the economy, combat the climate crisis and recover biodiversity. Page 5*

Highway Operational Standards

- *Cambridge City Council currently manages the tree stock within Cambridge City on behalf of Cambridgeshire County Council. There are some 10,400 street trees within Cambridge City. Page 37*
- *The Highway Authority recognises that trees on the highway form an important part of the natural landscape providing aesthetic, ecological and environmental benefits. To that end the Council is keen to support and encourage local communities that wish to plant trees in their area. In the first instance please contact the Local Highway Officer for your area. Page 39*

Climate and environment strategy 2022[20]

Ambition

Our ambition is to deliver net zero carbon emissions for Cambridgeshire by 2045, and support communities and our natural environment to adapt and thrive as the climate changes (page 6).

Principles

- *Net Zero Cambridgeshire 2045: Our principles in practice.*
  - *Leadership and collaboration.*
    - *We will use the land we own to deliver tree planting and other improvements to green space to maximise the carbon sequestration potential. page 10*

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[18] https://www.cambridgeshire.gov.uk/residents/climate-change-energy-and-environment/climate-change-and-environment-strategy

[19] https://www.cambridgeshire.gov.uk/asset-library/Interim-Corporate-Tree-and-Woodland-Strategy-and-Action-Plan.pdf

[20] https://www.cambridgeshire.gov.uk/asset-library/part-1-climate-change-and-environment-strategy-2022.pdf

Vision

- *Our communities will be more resilient to the impacts of climate change and will have space for nature to thrive.*
- *Our health will be better, and we will have easy access to sustainable, local transport and green space(Page 11).*

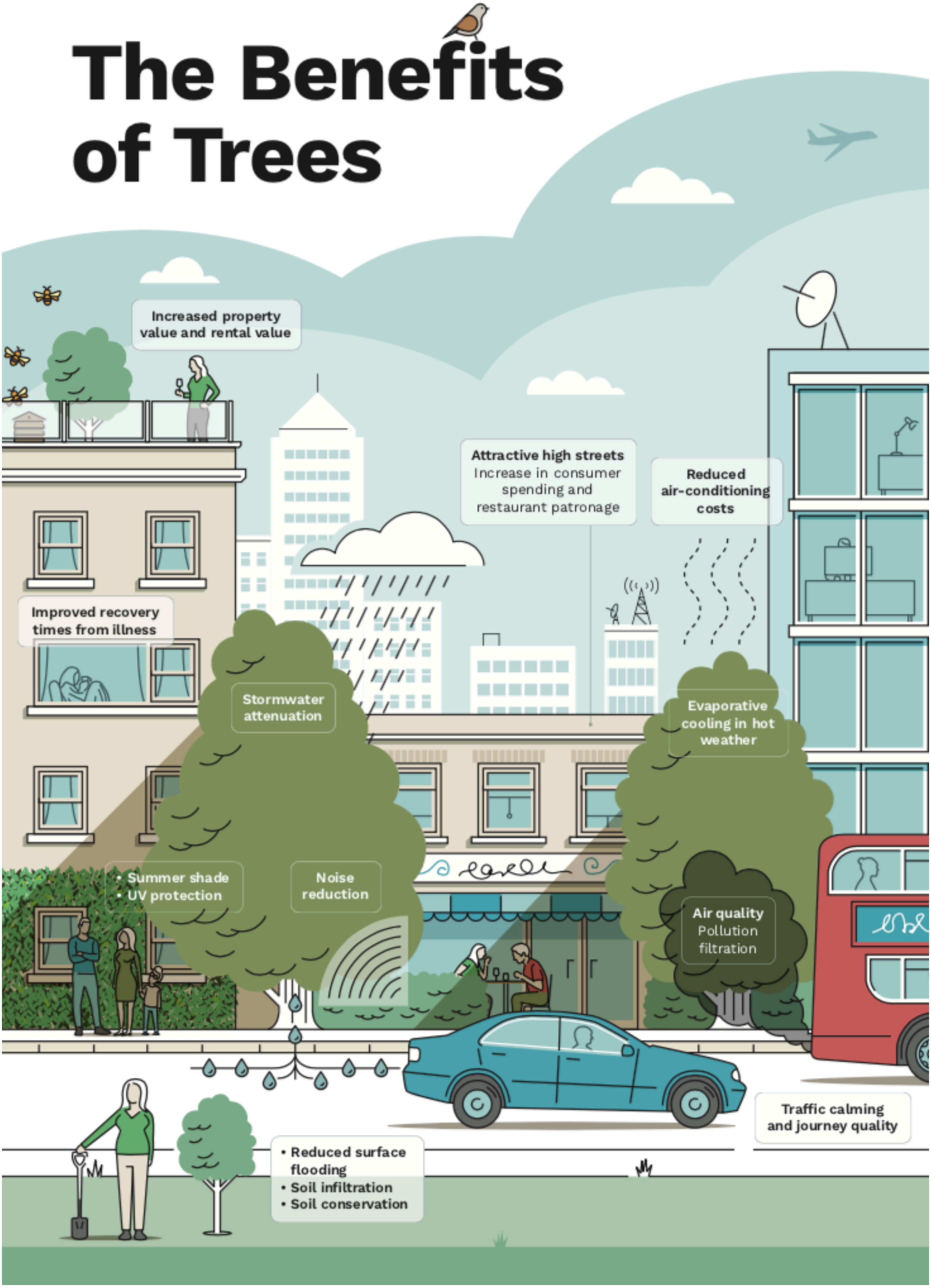
Priorities

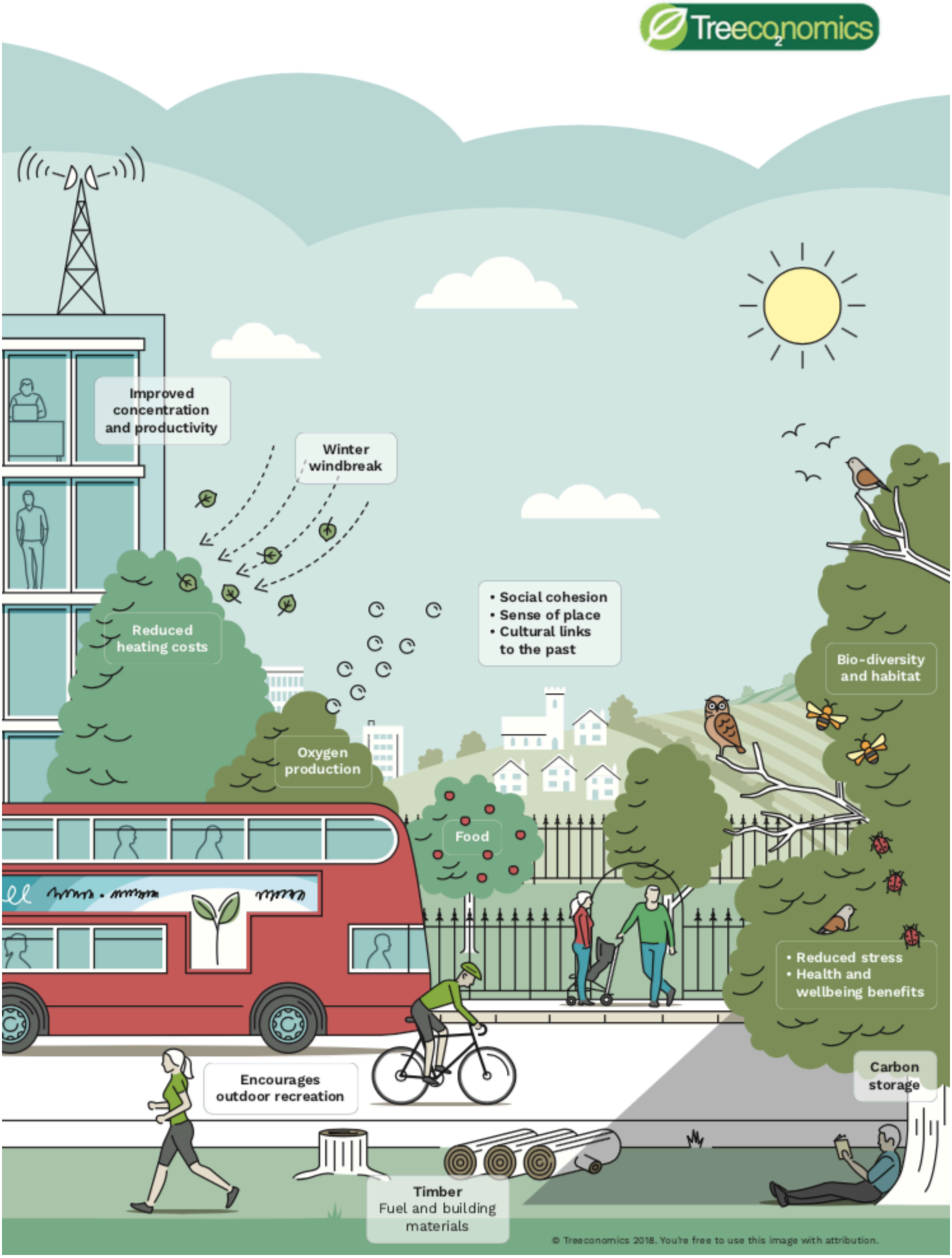
- *Manage climate risk and develop climate resilient services, people, places and infrastructure.*
- *Ensuring sustainable land use and green spaces.*
- *Benefiting nature and biodiversity. Page 14*

Target

- *Improve our biodiversity across the Council estate by 2030.*

The Benefits of Trees





Treeconomics
Improved concentration and productivity
Winter windbreak
Reduced heating costs
Oxygen production
• Social cohesion
• Sense of place
• Cultural links to the past
Bio-diversity and habitat
Food
• Reduced stress
• Health and wellbeing benefits
Carbon storage
Encourages outdoor recreation
Timber
Fuel and building materials
© Treeconomics 2018. You're free to use this image with attribution.

3.0 Methodology

To gather a collective representation of Cambridge's urban forest across both public and privately owned land, an i-Tree Eco (v6) plot-based assessment was undertaken. 203 randomly allocated plots of 0.04ha (400m^2) were surveyed, representing 0.2% of the total study area (4,068 ha). This equates to 1 plot every 20.04 ha. For comparison with other i-Tree Eco studies, please see Table 2 (below). The data collected for these plots is extrapolated to represent the whole study area. The following information (below) was recorded for each plot.

Plot Characteristics

Land use, ground cover, % tree cover, % shrub cover, % plantable space, % impermeable surface.

Shrub Characteristics

Shrub species, height (m), % missing and % cover of total shrub area.

Tree Characteristics

Tree species, height (m), trunk diameter at breast height (DBH), canopy spread, the health and fullness of the canopy, light exposure to the crown, distance and direction to the nearest building and life expectancy (LE).

This data was collected by a team of trained volunteers and arboricultural professionals during Summer 2020. Due to the nature of the sampling method, 468 plots were created for the project which included training and back up plots, the aim, to survey a minimum of 200 plots. Through GIS analysis of inaccessible plots, 203 plots were successfully surveyed. The full methodology for the GIS desktop analysis can be found within the appendices of this report.

Study Location	Plots per area
Petersfield	1 plot per 2.7 ha
Cambridge	1 plot per 20.0 ha
Torbay	1 plot per 26.0 ha
Plymouth	1 plot per 28.5 ha
Inner London	1 plot per 155.0 ha
Outer London	1 plot per 245.0 ha

Table 2: Comparison of plots per area in different study locations.

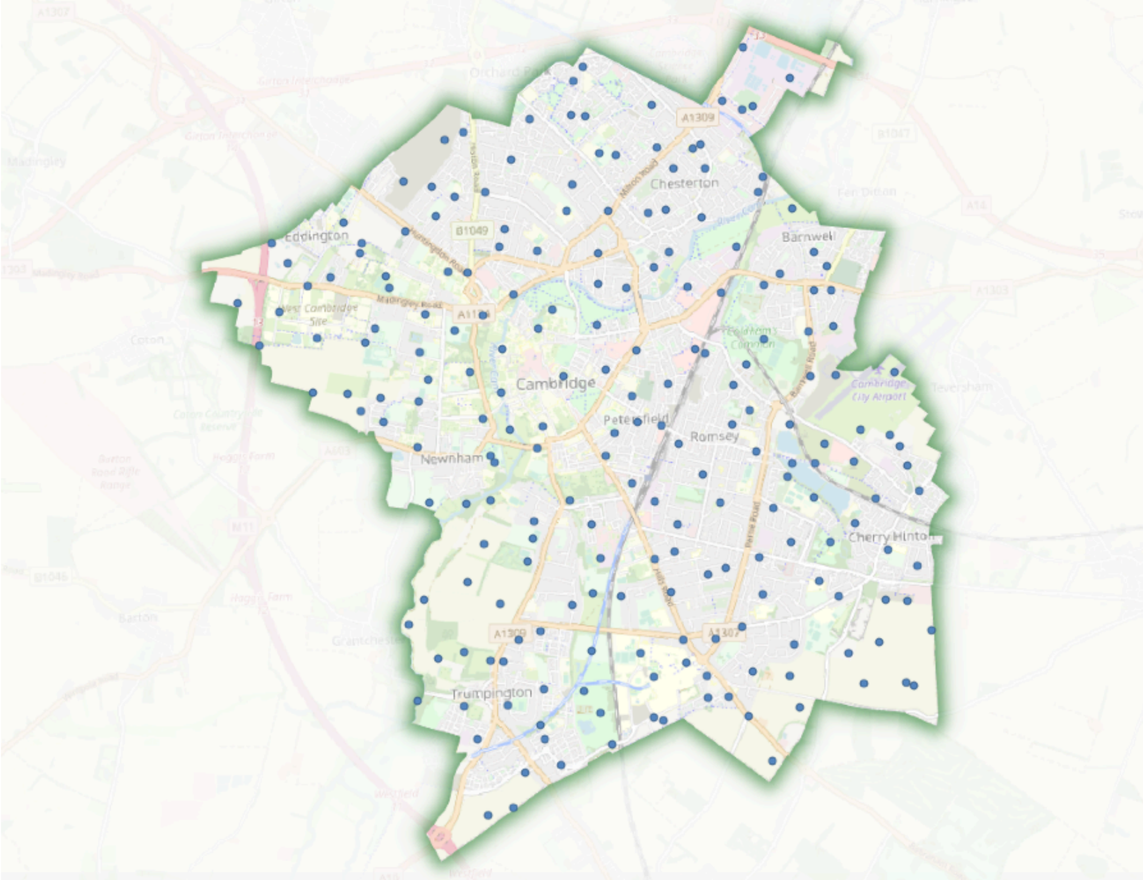


Figure 1. Sample plot distribution across study area.

The plots were randomly allocated within a grid to ensure a statistically significant distribution across Cambridge, they fall on both public and private land. While most areas could be accessed with permission, some could not. In the event that the plot landed in an area that was inaccessible, a desktop survey using GIS or a back-up plot was used (back-up plots are randomly allocated within the same grid square as the original) which allowed the full number of 203 plots to be surveyed.

Data Limitations

While Cambridge's trees provide a plethora of benefits, the figures presented in this study represent only a portion of the total value of the city's trees. i-Tree Eco does not quantify all of the services that trees provide; such as moderating local air temperatures, reducing noise pollution, improving health and well-being, providing wildlife habitat and, even, their ability to unite communities. Hence, the value of the ES provided in this report are conservative estimates. Furthermore, the methodology has been devised to provide a reliable representation of the trees and shrubs within Cambridge's urban forest in 2020This report should be used only for generalised information on the urban forest structure, function, and value. Where detailed information for a specific area (such as an individual park, street or ward) is required, further survey work should be carried out.

	Reference Values & Methodology Notes for Calculations
Number of Trees	The sample inventory figures are estimated by extrapolating from the sample plots and scaling up to the study area. For further details see the methodology section below.
Total Canopy Cover	The area of ground covered by the leaves of trees and shrubs when viewed from above (not to be confused with leaf area which is the total surface area of leaves).
Capital Asset Value for Amenity Trees (CAVAT)	A valuation method with a similar basis to the CTLA Trunk Formula Method, but one developed in the UK to express a tree's relative contribution to public amenity and its prominence in the urban landscape.
Replacement Cost	The cost of having to replace a tree with a similar tree) using the Council of Tree and Landscape Appraisers (CTLA) Methodology guidance from the Royal Institute of Chartered Surveyors.
Carbon Storage	The amount of carbon bound up in the above-ground and below-ground parts of woody vegetation.
Carbon Sequestration	The annual removal of carbon dioxide from the air by plants. Carbon storage and carbon sequestration values are calculated based on DECC figures of £70 per Tonne for 2021.
Pollution Removal	This value is calculated based on the UK social damage costs for 'Road Transport Outer Connurbation': £11.74 per kg (nitrogen dioxide), £6.79 per kg (sulphur dioxide), £220.122 per kg (particulate matter less than 2.5 microns).
Avoided Runoff	This value is based on the amount of water held in the tree canopy and re-evaporated after the rainfall event. The value is based on an average volumetric charge of £1.5655 per cubic metre and includes the cost of avoided energy and associated greenhouse gas emissions. Costed as per Anglian Water charges for surface water and sewerage; https://www.anglianwater.co.uk/account-and-bill/tariffs-and-charges/standard-rates/
Total Annual Benefits	Sum of the monetary values of carbon sequestration, pollution removal and avoided runoff. Carbon storage is not included since it is not an annual benefit, but rather an ecosystem service that has already been done.

Table 2: Calculations summary.

4.0 Results

The findings of the Cambridge i-Tree Eco project are detailed throughout this chapter. To enable comparisons with other studies throughout the UK, Table 2 (below) reports key total figures per unit of canopy for Cambridge, Newport, Torbay and London.

	Cambridge	Newport	Torbay	London
Units of canopy cover (ha)	**540**	582	765	22,300
Plot density	**1 per 20 ha**	1 per 24 ha	1 per 26 ha	1 per 221 ha
Carbon storage per unit of canopy	**163 tonnes**	130 tonnes	128 tonnes	106 tonnes
Carbon sequestration per unit of canopy	**3.8 tonnes**	3.6 tonnes	4.3 tonnes	3.5 tonnes
Pollution removal per unit of canopy	**119 Kilograms**	130 Kilograms	65 Kilograms	100 Kilograms
Avoided runoff per unit of canopy	**181 m^3**	151 m^3	-	153 m^3

Table 2: Outputs from Cambridge's i-Tree Eco study compared with three other cities.

4.1 Structure and Composition of Cambridge's Urban Forest

The structure of the urban forest is vital to maintaining and enhancing biodiversity within cities. Diverse forests have the potential to provide habitats for a greater range of insects, birds, mammals, and other creatures with healthier soils and populations of trees at a lower risk from pests and disease. This section of the report will illustrate the current species diversity, size distribution alongside other characteristics of Cambridge's urban forest. This evidence base can be utilised when making decisions around future planting and management of existing trees.

4.1.1 Ground Cover & Land Use

Ground cover in Cambridge (as measured using i-Tree Eco) consisted of approximately 55.0% permeable 'green space', such as grass and soil. Apart from a very small percentage (1.1%) of water, the remaining ground cover was made up of non-permeable surfaces such as brick, asphalt and concrete. These 'hard' surfaces absorb heat and contribute to a general warming of the urban environment, and the amount will continue to increase due to housing development.

The surveyed plots indicate that the most dominant land-use type in Cambridge is residential at 37.5%. Agriculture represents 16.3% and Parkland accounts for 6.9%.

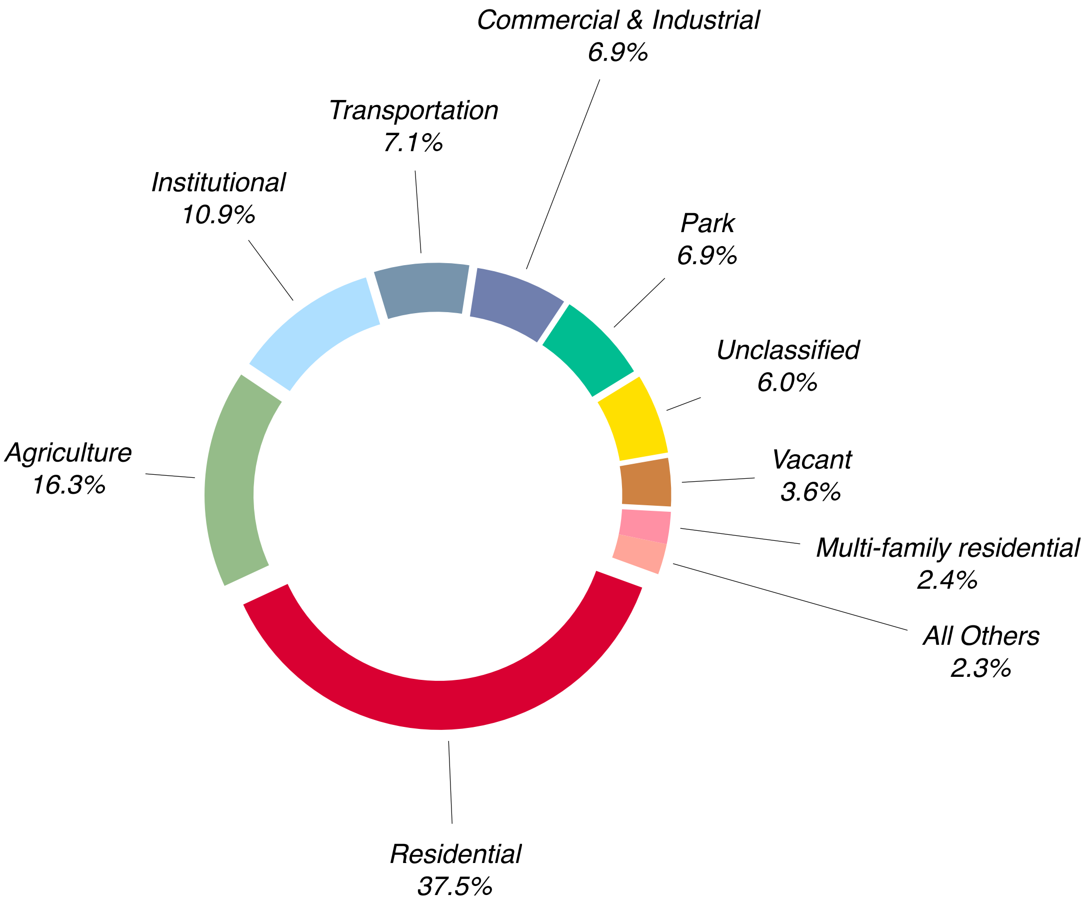


Figure 4: Percentage land use in Cambridge estimated by Eco.

4.1.2 Tree Species and Diversity

Cambridge benefits from a wide range of tree species, providing a strong foundation for future urban greening and development. This survey of Cambridge's urban forest identified 49 genera and 105 species, with an associated diversity index score of 4.1 according to the Shannon Weiner Index (usually an index of 1 is considered low, and 4 is considered high).

The three most common tree genera include *Crataegus, Prunus and Acer.* These three genera represent 34.2% of the tree population with 12.5%, 11.1% and 10.6% respectively.

Within the *Crataegus* genus, the most common species is *Crataegus monogyna* (hawthorn) which represents 11% of the population.

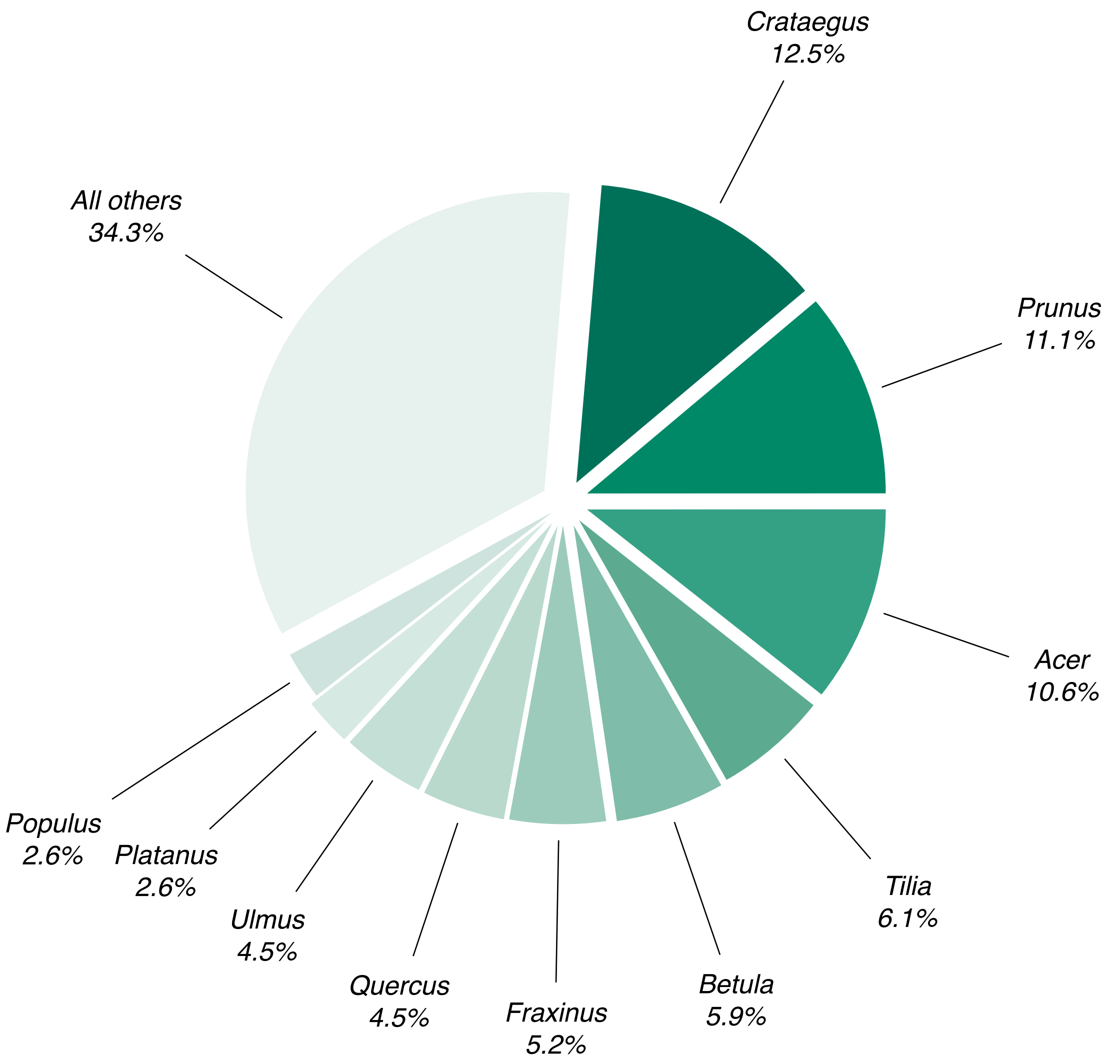


Figure 5: Percentage of the population represented by the top 10 tree genera.

Santamour's 10-20-30 rule (Santamour, 1999) may be considered a useful tool in planning for maintaining diversity of species; the 10-20-30 rule is applied by some urban foresters as a rough guide to maintain a diverse population. This 'rule' suggests that no single species should represent more than 10% of any population, no single genus should represent more than 20% of a population and no single family should represent more than 30% of a population. This practice has been discussed by other authors, who have further examined the evidence and practicalities (Kendal, 2014; Sjöman *et a*l., 2012). In future it may also be useful to consider further diversifying the population towards meeting Barker's benchmark of 5% per species (Barker, 1975).

In Cambridge, no single genus represents more than 20% of the population. At species level, *Crataegus monogyna* (hawthorn) represents more than 10% of the population. Using this information, selection of species for future planting in Cambridge can be focussed on reducing the reliance on *Crataegus monogyna*, and other species which already maintain a high proportion of the population. Increasing diversity will help to improve the resilience of the urban forest and limit the impact from pests and diseases, climate change and other stressors to the tree population. Appendix II contains a full list of species.

Species which originate from more distant regions to each other may be more genetically dissimilar and their presence may therefore increase resilience to environmental perturbations. The tree population within Cambridge's urban forest represents a rich community of trees, with 49 genera and 105 species identified. Some of Cambridge's urban forest records provided were at the genus level only, indicating that species variation may actually differ from the 105 species indicated. This should be considered when indicating species richness. Tree species from four continents are represented in Cambridge's urban forest. Most of the species are native to Europe and Asia (see Figure 6 below). However, further work would be required to assess the condition, size and populations of these trees and to provide recommendations on the best species to choose for any future plantings.

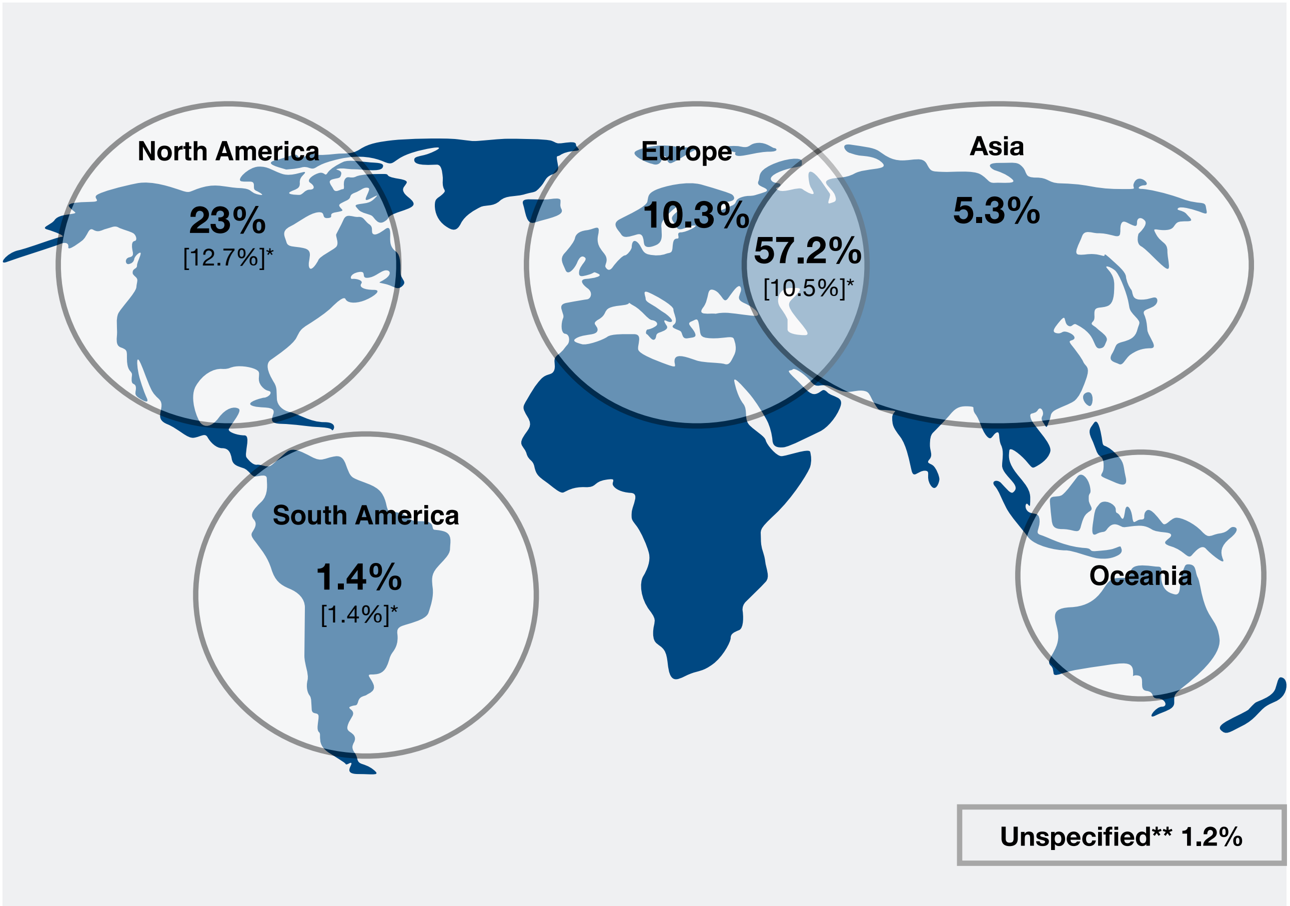


Figure 6: Origin of tree species (share of trees native to different geographical regions). Overlaps indicate origins within both continents.

*In these cases the proportion in brackets may include additional regions.
**Whilst there are still a few species whose origin remains unknown, most of these are hybrid species with a likely parentage from two zones rendering the concept of regional origin mute.

4.1.3 Size Distribution

Size class distribution is an important aspect to consider in managing a sustainable and diverse tree population, as this helps ensure that there are enough young trees to replace those older specimens that are eventually lost through old age or disease. It is also relevant in terms of benefit delivery, as generally larger trees deliver greater benefits.

In Cambridge's urban forest, trees were sized by diameter at breast height (DBH). Figure 7 (below) shows the percentage of the tree population for the ten most common tree genera by DBH class. The chart represents a typical size class contribution for an urban area, with percentage composition declining as size increases. There is, however, some variation between genera. If new plantings are made up of smaller stature species there will be a lack of larger trees in the future. To maintain or increase canopy cover and tree benefits at or above current levels then more trees capable of attaining larger statures will need to be planted and maintained.

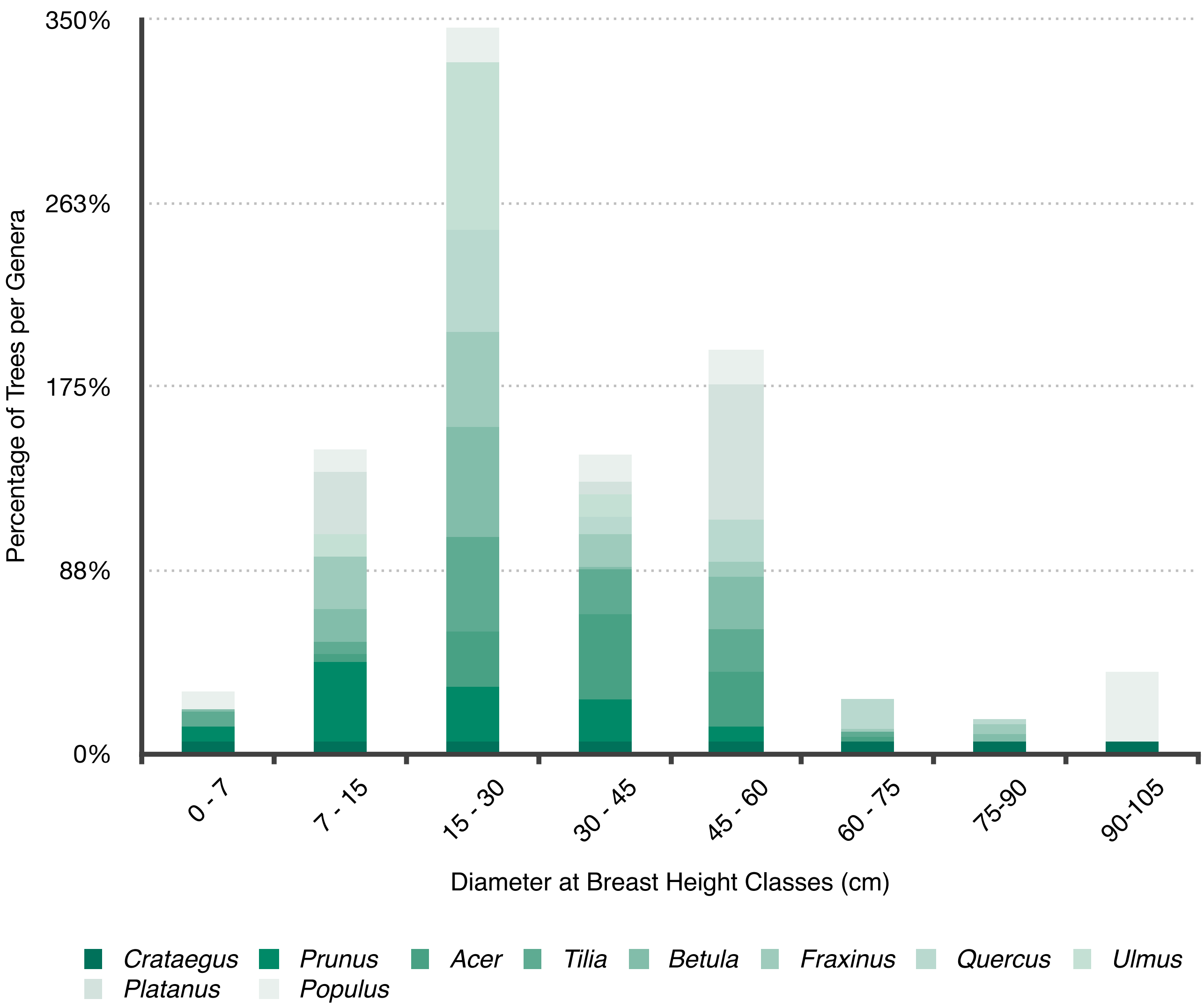


Figure 7: Percentage of tree population by DBH class by genus.

4.1.4 Canopy Cover

Canopy cover (also referred to as tree canopy cover, urban tree cover and urban canopy cover), is defined as the area of leaves, branches, and stems of trees covering the ground when viewed from above. It is a two dimensional metric, indicating the spread of the crown across an area. It is not to be confused with Leaf Area Index (LAI), which is a measure of the number of layers of leaves per unit area of ground (although canopy cover studies can be used to estimate LAI).

Measuring canopy cover is important because it is an easy-to-understand concept that is useful in communicating messages about our urban forests with the public, policy makers and other stakeholders. Quantifying tree canopy cover has been identified by many authors (Britt and Johnston, Escobedo, Nowak and Schwab) to be one of the first steps in the management of the urban forest.

In 2013 a report was completed using ProximiTREE, Ezytreev, and aerial photography stereo images (ADAS, 2013). This found that total canopy cover (trees and large shrubs) in Cambridge was around 17%, and Cambridge's Tree Planting Strategy (2016) states the goal of increasing this to 19% by 2030.

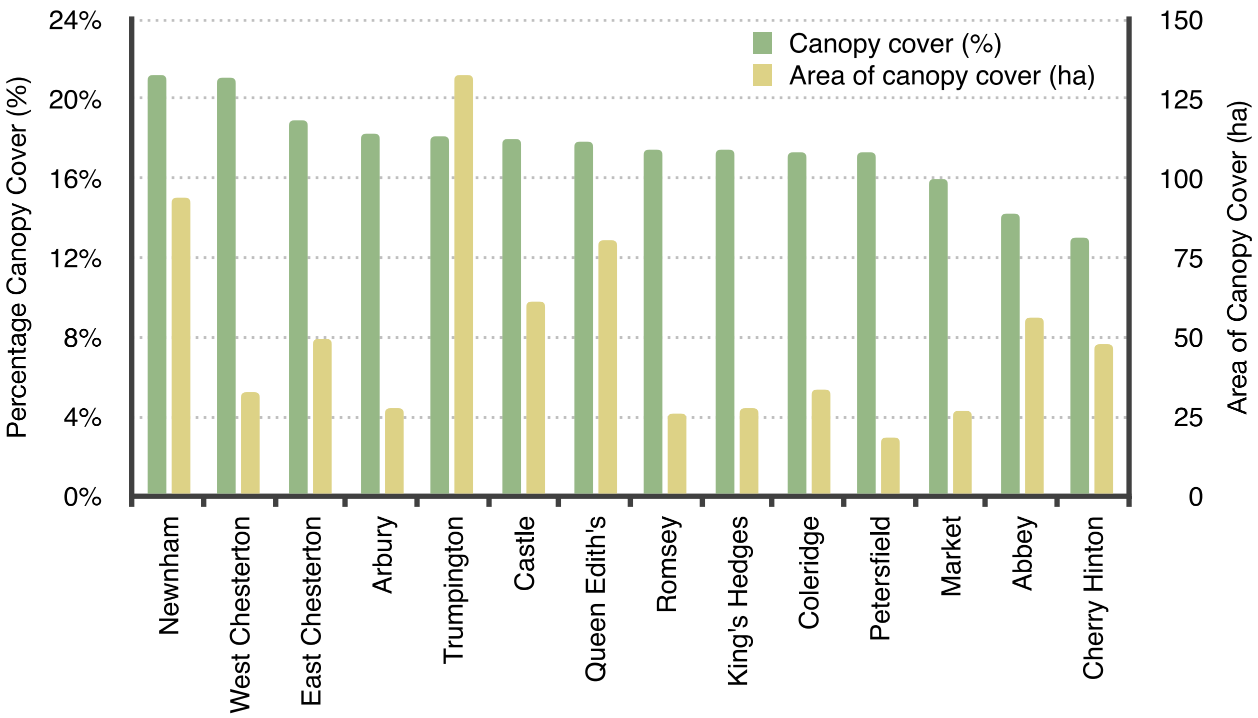


Figure 9: Percentage canopy cover and canopy cover by area of each ward from i-Tree Eco.

Eco generates both tree cover and shrub cover values, which can be combined to give the total canopy cover of both trees and shrubs. This informative data gives an overview of the total biomass coverage. Eco's tree cover for Cambridge is 13.3% and shrub cover is estimated at 6.8%, giving a total canopy cover of 20.1%. Despite these values being seemingly misaligned, it can be understood when their differing approaches and methodologies are considered. For example, there will be some overlap of tree canopy and shrub cover in Eco Sample surveys, which cannot be separated by i-Tree before extrapolation, conversely, ProximiTREE data includes shrubs over 1.2m in height only.

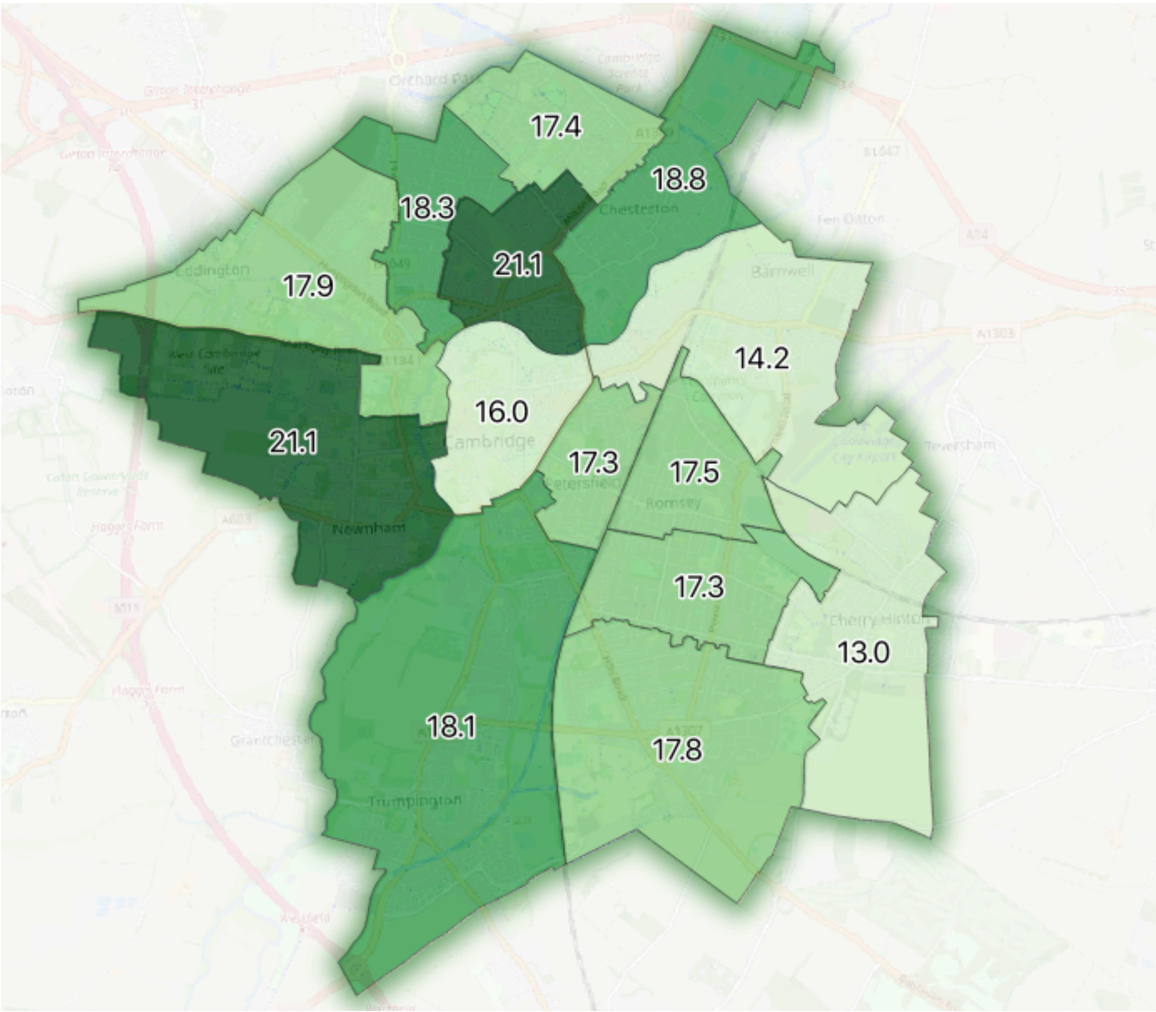


Figure 10: Map of Cambridge's canopy cover by ward from National Tree Map Sentinel data (%).

Shrubs do make contributions in terms of ES, however, in most cases, trees far exceed these, and therefore tree cover should be reported within targets and strategies as this is the very resource local authorities are aiming to increase. It would be highly beneficial to Cambridge to seek to improve the level of canopy cover over the long term through priority planting schemes and maintenance of the current tree stock.

4.1.5 Leaf Area and Dominance

Leaf area is an important metric because the total surface area of a tree canopy is directly related to the amount of benefit provided. Generally the larger the canopy and its surface area, the greater the amount of air pollution or rainfall which can be held in the canopy of the tree.

Within Cambridge's urban forest, total leaf area is estimated at 3,470 ha. If all the leaves within the tree canopies were spread out, they would cover approximately 85% of the total study area (4,068 ha). It could be an interesting target to aim to achieve 100% leaf area coverage for the study area.

The three most dominant genera in terms of leaf area are *Tilia* (Lime) *Acer* (Maple) and *Fraxinus* (Ash) accounting for 13%, 11% and 9% of the total leaf area respectively.

Tilia platyphylos (Large leaved lime) alone accounts for 9.3% of the total leaf area for all trees.

Figure 11 (below) shows the top ten dominant trees' contributions to total leaf area. In total these ten genera, representing 63% of the tree population, contribute over 70% of the total leaf area.

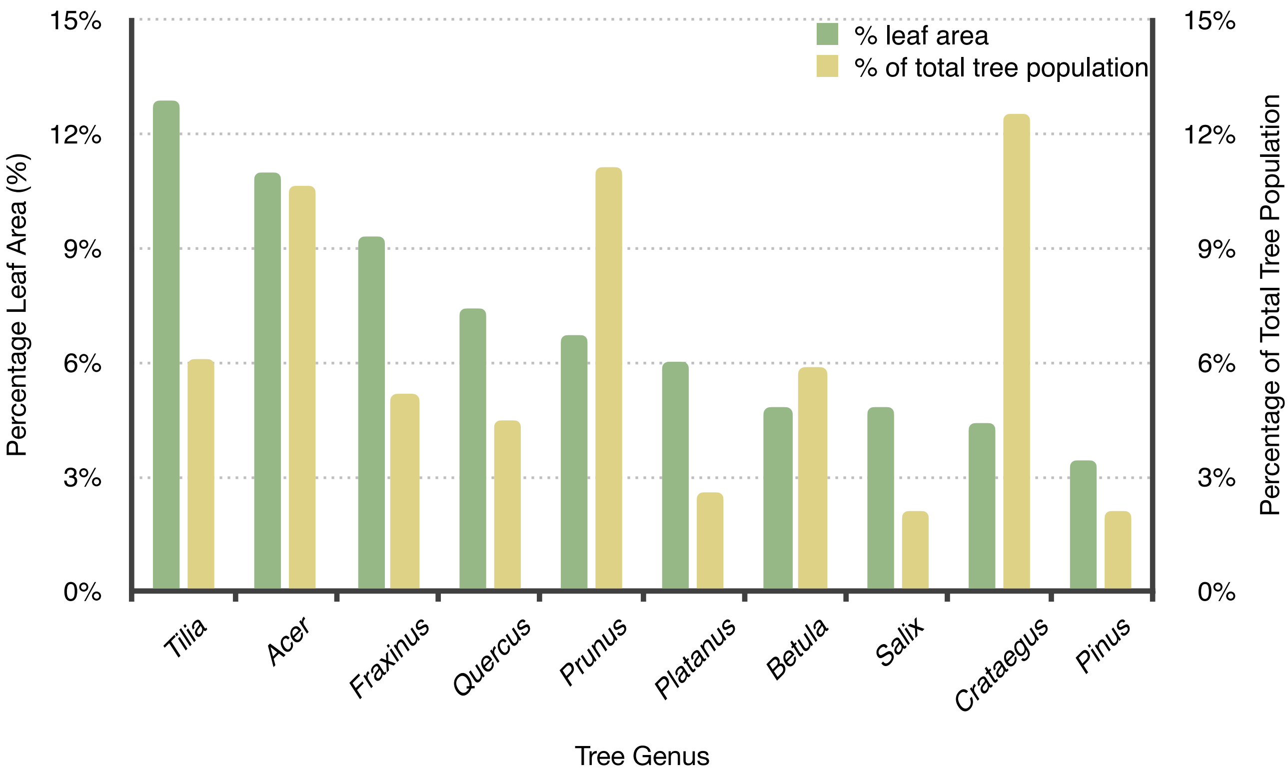


Figure 11: Percentage leaf area and population of the ten tree species with the highest leaf area.

4.1.6 Potential Pests and Diseases

Pests and diseases pose a serious threat to urban forest health and sustainability. Historically, outbreaks have had a significant impact on urban trees and the wider tree population. Dutch Elm Disease for instance has killed approximately 30 million trees in the UK since the 1960s. Pests and diseases can incur significant financial costs for reactive tree management and associated replacement costs. It is estimated that the cost of managing oak processionary moth (*Thaumetopoea processionea*) in London is £1.2 million per annum. As such, it is vital that the risk posed by new and emerging pests and diseases is assessed, in addition to those already present. In Cambridge, assessment of these risks has included developing risk matrices (Table 3 and 4 below) for determining the probability of establishment of a select number of pests and diseases not currently present in the UK, as well as those that are present in the UK (Table 5).

Prevalence	0-5 %	6-10 %	>10 %
Not in the UK			
Present in the UK			
Present in Cambridge			

Table 3: Risk matrix used for the probability of a pest or disease becoming prevalent in Cambridge's urban forest on a single genus (one or more species).

Prevalence	0-25 %	26-50 %	>50 %
Not in the UK			
Present in the UK			
Present in Cambridge			

Table 4: Risk matrix used for the probability of a pest or disease becoming prevalent in Cambridge's urban forest on multiple genera.

Pest/Pathogen	Species affected	Prevalence in the UK	Prevalence in Cambridge	Risk of spreading to Cambridge	Population at risk (%)
Acute oak decline	*Quercus robur, Q. petraea, Q. cerris, Q. fabri, Q. ilex, Q. aliena* var. *accuserrata, Q. palustris, Q. pyrenaica, Q. rubra, Q. coccinea, Q. nigra*	Central and SE England, Welsh borders and SE Wales	May be present	High – already present in this region	**2.1%**
Asian longhorn beetle	Many broadleaf species (see appendices)	None (previous outbreaks contained)	None	Medium risk – climate may be suitable	**40.4%**
Bronze birch borer	All *Betula spp.*	None	None	Medium risk	**5.4%**
Canker stain of Plane	*Platanus x acerifolia, Platanus occidentalis, Platanus orientalis*	None	None	Medium risk – likely to establish	**<0.1%**
Chalara dieback of ash	*Fraxinus excelsior, F. excelsior* 'Pendula', *F. angustifolia*	Occurs in most parts of the UK	Present	High - already present	**4.5%**
Citrus longhorn beetle	Many broadleaf species (see supplemental report)	None	None	Medium risk of spread upon entry to the UK	**47.5%**
Dutch elm disease	*Ulmus spp.*	Occurs in all parts of the UK	May be present	High – already present in this region	**4.5%**
Eight-toothed spruce bark beetle	*Picea abies, Pinus spp., Pseudotsuga spp., Larix spp., Abies spp., Picea spp.*	Present (limited)	None	Medium risk – present in the UK	**2.4%**
Elm zigzag saw fly	*Ulmus procera, U. glabra, U. minor*	Present in SE England and East Midlands	May be present	High – already present in this region	**4.5%**
Emerald ash borer	*F. excelsior, F. angustifolia*	None	None	Medium risk (imported wood)	**4.5%**
Horse chestnut bleeding canker	*Aesculus hippocastanum*	Present in all parts of GB	Present	Already present	**<0.1%**
Oak processionary moth	*Quercus spp.*	Established in Greater London and some surrounding counties	May be present*	Medium, small colonies are containable	**2.1%**
Phytophthora lateralis	*Chamaecyparis formosensis, Chamaecyparis lawsoniana, Chamaecyparis obtuse, Chamaecyparis pisifera, Rhododendron spp., Thuja plicata, Thuja occidentalis, Pseudotsuga menziesii, Taxus brevifolia*	Occurs across the whole of the UK	May be present	High – already present in the UK	**1.8%**

Pest/Pathogen	Species affected	Prevalence in the UK	Prevalence in Cambridge	Risk of spreading to Cambridge	Population at risk (%)
Pine processionary moth	*Pinus nigra, Pinus sylvestris, Pinus pinea, Pinus halepensis, Pinus pinaster, Pinus contorta, Pinus radiata, Pinus canariensis, Cedrus atlantica, Larix decidua, Pseudotsuga menziesii*	None	None	Medium risk – South England and Wales could be most favourable	**1.6%**
Xylella fastidiosa subsp. *multiplex***	*Acacia dealbata, Acacia saligna, Acer pseudoplatanus, Cercis siliquastrum, Elaeagnus angustifolia, Ficus carica, Fraxinus angustifolia, Metrosideros excelsa, Olea europea, Platanus occidentalis, Prunus spp., Quercus suber Quercus robur, Ulmus glabra, Q. rubra,*	None (one previous interception in the UK)	None	Medium risk – climate may be suitable	**13.5%**

Table 5: The significance of a range of existing and emerging pests and diseases to Cambridge's urban forest.

Ash Dieback

Ash Dieback[21] (*Hymenoscyphus fraxineus*) is a major problem currently faced in the UK. This vascular wilt fungus causes the dieback and can often lead to the death of ash trees. Ash Dieback is harmless in its native range in Asia, associating with native ash species including *Fraxinus mandshurica*. However, other *Fraxinus* species, particularly Ash *(Fraxinus excelsior*) has shown to be highly susceptible to the pathogenicity of *H. fraxineus*. Whilst thought to have been introduced to Europe in 1992, it was first discovered in the UK at a nursery in Buckinghamshire in 2012 (DEFRA, 2013). It has had a major impact upon the ash population in several countries, and since being found in the UK, the rate of infection has increased at a steady rate and widely present in continental Europe and Ireland. The greatest public risk from Ash dieback is likely to be found alongside transport routes or in areas regularly used by people (e.g. parks, along footpaths). Ash trees on these sites can be significant stress factors, such as high salt content in soils due to winter salting, which can increase disease susceptibility.

The risk to the trees in Cambridge is very high, as Ash Dieback is already present in the area. *Fraxinus* accounts for 4.5% of the population (over 11,000 individual trees), and species include *F. excelsior*, *F. angustifolia*, and *F. quadrangulata*.

[21] Previously known as Chalara Dieback of Ash

Fraxinus, the 6th most common genus, the second highest carbon storing genus, and the third best at intercepting stormwater and removing pollution from the atmosphere. They are a significant presence in Cambridge and effective replacement of anticipated tree losses should be prioritised to prevent a large decrease in canopy cover and ecosystem service provision over the next decade. The total replacement cost for these trees is over £12.6 million.

<u>Selection of Pests and Diseases for Analysis</u>

Individual pests and diseases were not actively identified during the survey work for the project. In assessing the impact of pests and diseases, estimates of tree numbers were compared with the listed susceptible species for each pest or disease. Information was sourced from Defra's plant health portal and pests and diseases were selected for assessment based on their level of priority or concern. This included those that can lead to tree death or pose a significant human health risk; further details on individual pests and diseases are provided in the appendix. It is to be noted that this is not an exhaustive list of pests and diseases that may be present or have the potential to affect Cambridge's urban forest should they enter into the UK. The information contained within Table 5 could be used to inform programmes to monitor the presence and spread of a pest or disease, and strategies to manage the risks that they pose.

<u>Management to Reduce this Risk</u>

Increasing the resilience of the urban forest as a whole by increasing tree species diversity may reduce the impact associated with some pests and diseases. Some pests and diseases not currently present in the UK, such as Citrus longhorn beetle (*Anoplophora chinensis*) could pose a threat to as much as 47.5% of Cambridge's urban forest and could devastate a wide range of urban trees species. Providing a greater diversity of tree species can increase the likelihood that more trees will not be susceptible to certain pests and diseases. Continuous monitoring of urban trees for signs of pests and diseases is key to their protection; ensuring this is built into seasonal survey work can lead to a quicker response time to the eradication of the pathogen before it becomes a problem.

4.1.7 Conclusions and Recommendations for Structure and Composition

Despite Cambridge already having 49 genera and 105 different species, there is room to improve the diversity and dominance and focus on larger stature, longer lived species. Genera diversity is high, at a species level future planting can focus on further improving species diversity to avoid reliance on a single species. Though *Tilia* is the most common genus, the most common species is *Crataegus monogyna* (hawthorn) which accounts for 11% of the population.

The tree size distribution across the city was fairly typical of most urban landscapes, indicating that 75% of the top 10 most common trees have a DBH of 7-30cm, and 19% are between 30-60. Trees with a DBH greater than 90cm were the least common, representing 3.7% of the total tree population and 0% of the top 10 most common species. It is important to note that typically larger trees provide more ecosystem benefits to communities.

There is a high number of *Ulmus* (elm) in Cambridge; approximately 9,540 trees which accounts for 4.5% of the total tree population and is the 8th most populous genus. All of the elms recorded are *Ulmus procera* (elm), which are particularly susceptible to Dutch elm disease (*Ophiostoma novo-ulmi*). The disease is present throughout the UK and sadly elm has sustained the greatest losses of all the elm species due to 'being the preferred food species of beetles spreading the fungus' (Forest Research, 2021a).

Fraxinus also makes up a large proportion of trees in Cambridge, with *Fraxinus* species accounting for approximately 11,040 trees (5.2% of the total tree population). *Fraxinus excelsior* (Ash) accounts for 5% of the total leaf area and is the most dominant species in that regard. Ash Dieback poses a serious threat to these trees and is predicted to cause 'significant damage to the ash population' (Forest Research, 2021b).

This study indicates that the tree density across Cambridge is 52 trees/ha, and the tree canopy cover is approximately 13%, with a further 7% of large and small shrub cover. Consistent, good management of these urban trees can help to ensure they remain healthy, and to minimise the pressures associated with city living which can increase trees susceptibility to pests and disease.

Given these findings, it is recommended that:

1. A wide variety of tree species are planted (with due consideration to local site factors) to increase diversity and reduce any over-reliance on dominant species identified as part of this study.

2. Protection for existing mature and maturing trees is of great focus, together with increasing the planting of large-stature trees, (where appropriate) to increase canopy cover and the provision of benefits.

3. It suggested that Cambridge should aspire to achieve 25% canopy cover by 2050. Part of this goal is achievable through protection and enhancement of existing trees (see 2 above). Targeted planting in areas with low existing canopy cover can help to achieve greater evenness and increase environmental equity throughout the city.

4. In order to implement and monitor these recommendations, and those that follow in further sections, it is also recommended that:
    i. Cambridge City Council carefully plan future tree planting locations and species selection to achieve the recommendations listed above.
    ii. Cambridge City Council continues to communicate and promote the benefits of their urban forest with the community. Online resources such as Webmaps can be a great way to illustrate this information and show distributions across the city.
    iii. Cambridge City Council should produce a strategic Urban Forest Masterplan (with a long term vision for 2100). This plan should set out how these and other recommendations can be measured, targeted to areas of greatest impact and need, and implemented. In addition the plan should set out criteria for a repeat assessment in 5-7 years to monitor progress.

5. Further investigation to identify barriers to planting and establishment of trees in the lowest performing wards.

6. Work to further the engagement of local people through a Tree Warden scheme, and encourage the monitoring and maintenance of newly planted trees by local volunteers to ensure the survival of young trees.

4.2 Ecosystem Service Provision of Cambridge's Urban Forest

Trees provide a wide range of services, and urban trees in particular are under significant pressures to perform. Air pollution in cities has been known to cause health problems, excess storm water run-off can cause flooding, and increasing built environments along with human activity in urban areas can raise temperatures to as much as 9°C compared to surrounding rural landscapes in the UK (Chartered Foresters, 2016). Trees are a significant advantage in the fight to reduce these issues and minimise the risks they present to people.

Cambridge's trees and green spaces are a critical resource securing a sustainable future for this vibrant city. The ES provided by trees are at the front line in the fight against climate change. Urban trees are crucial to making city living sustainable, and can contribute to meeting global and national targets, such as limiting the rise of global temperatures to below 2 °C (The Paris Agreement), reaching carbon net neutrality by 2050 (UK Climate Change Act), and cutting greenhouse gas emissions by 68% by 2030 (The UK's Nationally Determined Contribution).

4.2.1 Air Pollution Removal

Poor air quality is a common problem in many urban areas, in particular along transport corridors. Air pollution caused by human activity has caused issues since the beginning of the industrial revolution. With increasing populations and industrialisation, large quantities of pollutants are produced and released into the urban environment. The problems caused by poor air quality are well documented, ranging from severe health problems in humans to damage to buildings.

Urban trees can help to improve air quality by reducing air temperature and directly removing pollutants (Tiwary *et al*., 2009). Trees intercept and absorb airborne pollutants on to the leaf surface (Nowak *et al*., 2000). Through removing pollution from the atmosphere, trees can reduce the risks of respiratory disease and asthma, thereby contributing to reduced healthcare costs (Peachey *et al*., 2009; Lovasi *et al*., 2008).

Trees emit volatile organic compounds (VOCs) that can contribute to ozone formation which is detrimental to human health. However, integrated studies have revealed that an increase in tree cover leads to a general reduction in ozone through a reduction in air temperature. Eco accounts for both reduction of ozone and production of VOCs within its algorithms and, as shown in Figure 12 (below), Eco estimated that Cambridge's urban forest contributes to a net reduction in ozone concentrations.

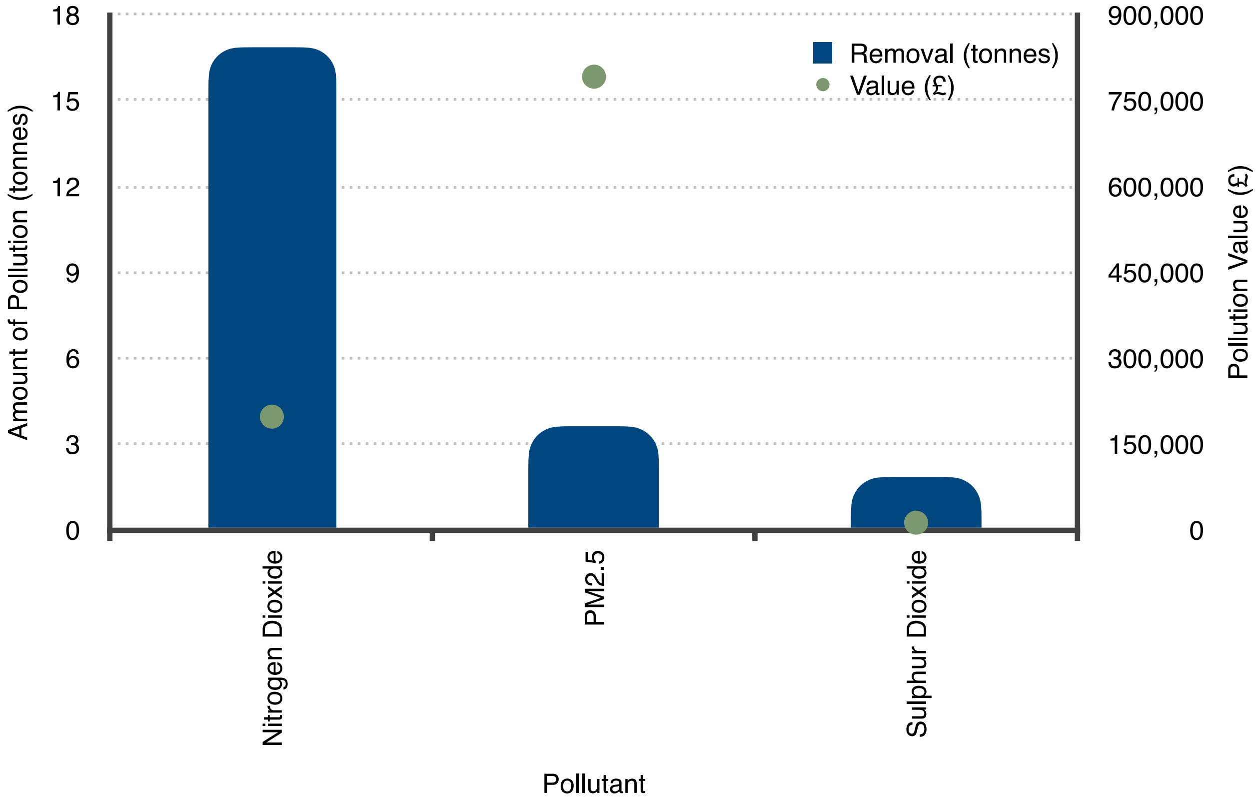


Figure 12: Value of the pollutants removed and quantity per-annum.

Across Cambridge it is estimated that the trees of the urban forest remove over 22.2 tonnes of pollutants from the atmosphere each year, with an associated value of £990,000. This includes nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and particulate matter 2.5µm (PM2.5). The valuation method uses UK social damage costs (UKSDC).

Tree cover, pollution concentrations, and leaf area are the main factors influencing pollution filtration and therefore increasing areas of tree planting have been shown to make further improvements to air quality. Furthermore, because filtering capacity is closely linked to leaf area, it is generally the trees with larger canopy potential that provide the most benefits.

Trees are also capable of removing carbon monoxide (CO) and ozone (O_3) from the atmosphere. For this study, pollution data was not available to calculate the amount of CO removed by trees, and i-Tree's methods of estimating Ozone levels[22] are not reflective of the UK environment. There is also no UK Social Damage Cost for ozone or carbon monoxide.

Therefore, the values of pollution removal should be considered an underestimation for the total pollution removal capabilities of the trees in Cambridge.

[22] Ozone removal is estimated to be 41.9 tonnes per year, however this is not included in this report as the i-Tree calculations derive from US data, and are not truly reflective of the UK. Trees remove mostly Ground Level Ozone, of which concentrations are highest over large land masses, in warm climates with low humidity, and when wind is light or stagnant (Air Central Texas, 2021).

Figure 13 shows the breakdown for the top ten pollution removing species in Cambridge's urban forest. As different species can capture different sizes of particulate matter (Freer-Smith *et al.*, 2005), it is recommended that a broad range of species should be considered for planting in any air quality strategy.

The three genera with the greatest pollution removal are *Tilia* (Lime) *Acer* (Maple) and *Fraxinus* (Ash). Of the *Tilia* genus, *T. cordata, T. platyphylos, T. tormentosa and T. X europaea* account for an estimated 13,100 individual trees and 6.1% of the tree population in total. The reason for the success of *Tilia* at pollution removal may be the age and size of the trees, as well as their morphology. *Tilia* are well known for their ability to remove pollution and have been a popular choice of street tree in many cities.

Typically the canopy of deciduous trees have a greater leaf area, however their leaves fall during the Autumn and Winter, they therefore cannot provide these benefits year round like their evergreen counterparts.

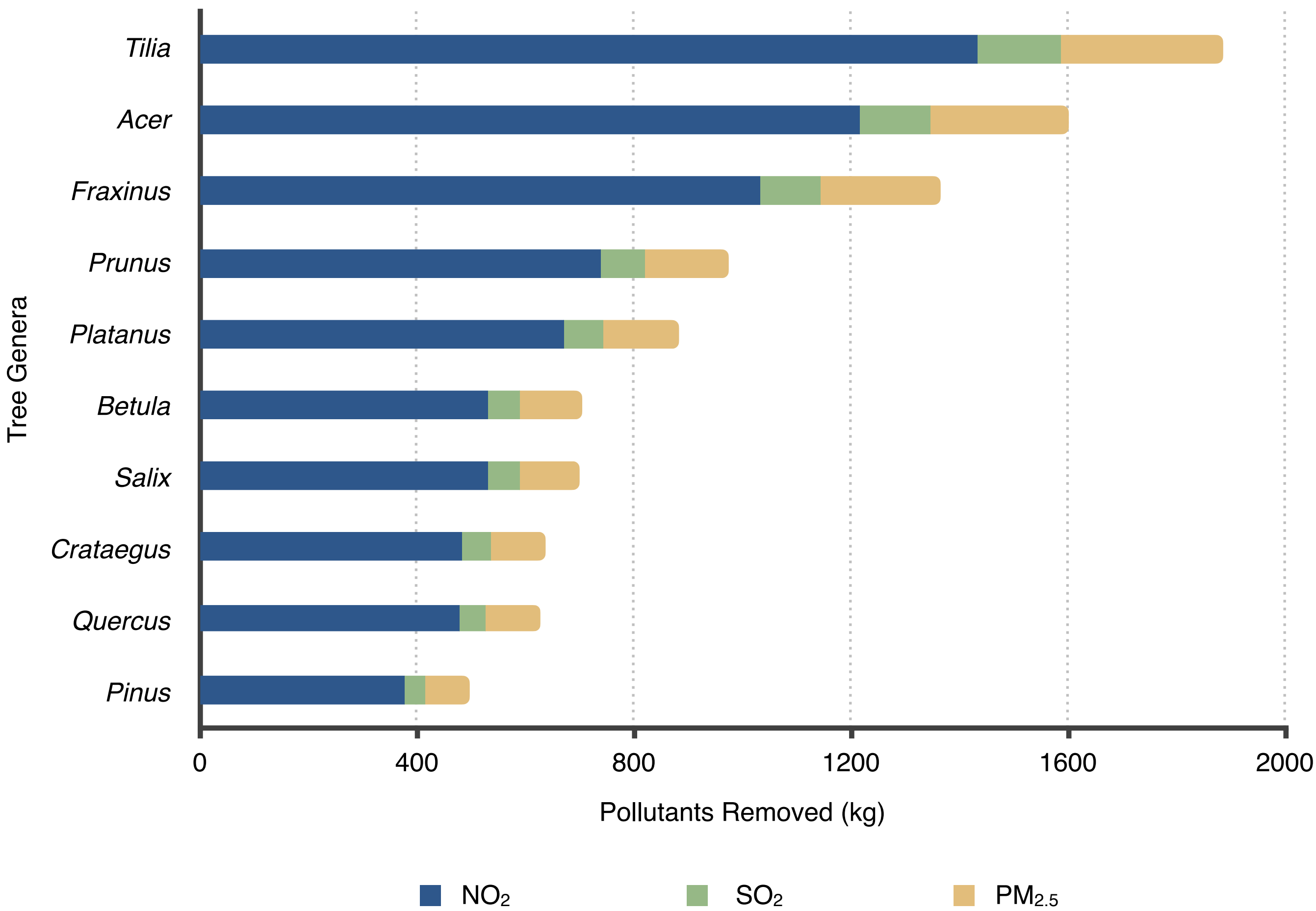


Figure 13: Pollution removal by tree genera.

4.2.2 Carbon Storage

The main driving force behind climate change is the concentration of carbon dioxide (CO_2) in the atmosphere. Trees can help mitigate climate change by storing and sequestering atmospheric carbon as part of the carbon cycle. Since about 50% of wood by dry weight is comprised of carbon, tree stems and roots can store up to several tonnes of carbon for decades or even centuries (Kuhns, 2008; Mcpherson, 2007). As trees die and decompose they release the stored carbon. The carbon storage of trees and woodland is an indication of the amount of carbon that could be released if all the trees were removed. Maintaining a healthy tree population will ensure that more carbon is stored than released.

Overall, the trees in Cambridge's urban forest store an estimated 88,000 tonnes of carbon with a value of approximately £22.6 million. Figure 14 (below) illustrates the top ten carbon-storing tree genera.

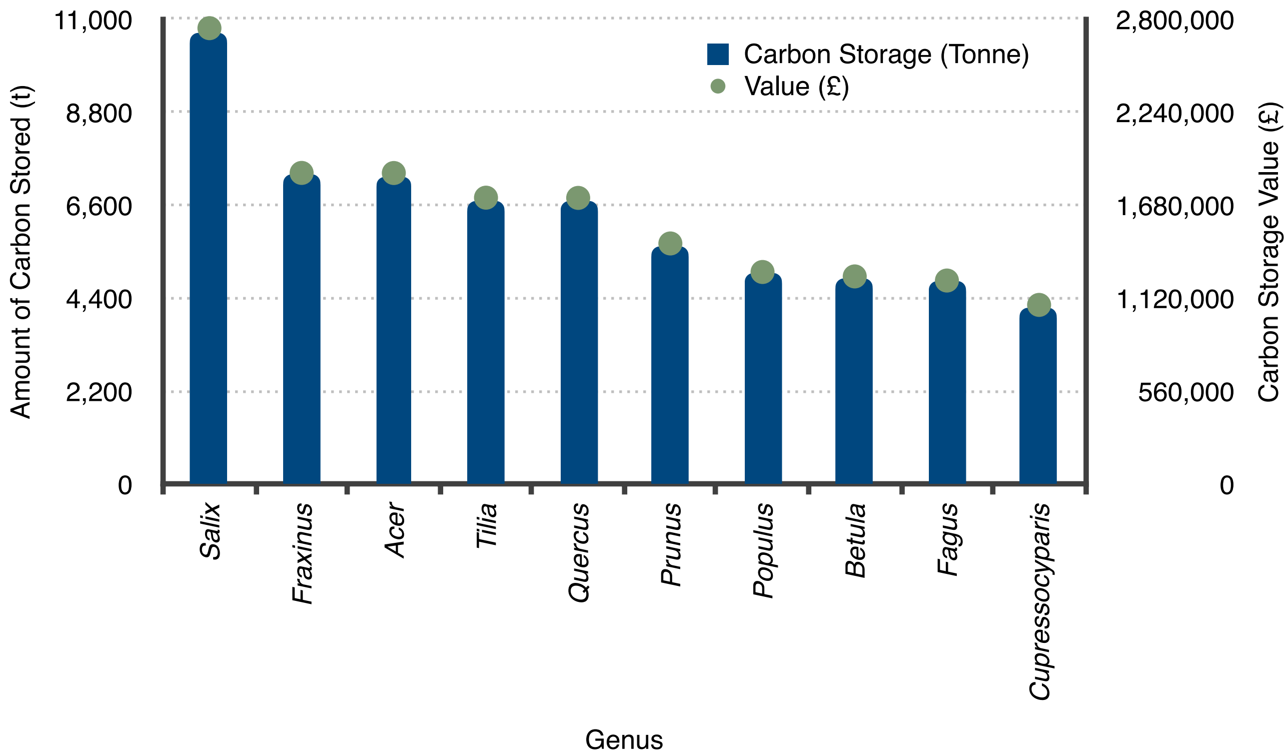


Figure 14: Carbon storage for top ten tree genera.

The three genera with the greatest carbon storage are *Salix* (Willow) *Fraxinus* (Ash) and *Acer* (Maple). Of the *Salix* genus, *S. alba, S. babylonica, S. caprea,* and *S. x sepulcralis 'Chrysocoma'* account for 4,500 trees and 2.1% of the population. Large trees store more carbon, and *Salix* have no trees identified with a DBH less than 15 cm, 35% are 60-75cm, and 25% are over 90 cm in diameter.

4.2.3 Carbon Sequestration

The trees within **Cambridge's urban forest sequester an estimated 2,040 tonnes of carbon per year, with a value of £524,000.** Table 6 (below) shows Cambridge's top ten genera in terms of annual carbon sequestration, and the value of the benefit derived from the sequestration of this atmospheric carbon.

Genus	Carbon Sequestration (tonnes/yr)	CO_2 Equivalent (tonnes/yr)	Carbon Sequestration (£/yr)
Tilia	230.7	846.1	£59,200
Betula	221.2	811.2	£56,800
Salix	189.6	695.3	£48,700
Platanus	129.2	473.8	£33,200
Acer	127.9	468.9	£32,800
Cupressocyparis	117.5	431.0	£30,200
Quercus	114.1	418.4	£29,300
Prunus	107.4	393.9	£27,600
Fraxinus	102.0	374.0	£26,200
Populus	69.6	255.0	£17,900
All Other Genus	**633.0**	**2,321.2**	**£162,000**
Total	**2,042.2**	**7,488.9**	**£524,000**

Table 6: Top ten carbon sequestration by genera.

The three genera with the greatest carbon storage are *Tilia* (Lime), *Betula* (Birch) and *Salix* (Willow). *Tilia x europaea* (lime) sequesters the most carbon each year, despite it being the sixth highest carbon storing species. In the study year, it added approximately 156 tonnes to the current *Tilia* carbon storage of 6,700 tonnes.

For comparison, the average newly registered car in the UK produces 34.3g carbon per km (NAEI, 2017). Total carbon sequestration in Cambridge's urban forest therefore corresponds to approximately 5,950,000 'new' vehicle km per year, which is equivalent to 1,140 people driving a car every year (Department for Transport, 2015; Department for Transport, 2019).

4.2.4 Avoided Surface Runoff

Surface runoff can be a cause for concern in many areas as it can contribute to flooding and is a source of pollution in streams, wetlands, waterways, lakes and oceans. During precipitation events, a proportion is intercepted by vegetation (trees and shrubs) while the remainder reaches the ground. Precipitation that reaches the ground and does not infiltrate into the soil becomes surface runoff (Hirabayashi, 2012).

In urban areas, large extents of impervious surfaces increase the amount of runoff. However, trees are very effective at reducing surface runoff (TDAG, 2014). Tree canopies intercept precipitation, while root systems promote infiltration and storage of water in the soil. Annual avoided surface runoff in Eco is calculated based on rainfall interception by vegetation, specifically the difference between annual runoff with and without vegetation.

The City of Cambridge is situated along the banks of the River Cam, where the land is level and low lying. Historically, the town was surrounded by wetlands, however these were drained as the town expanded. The impermeable bedrock underlying the city means water which permeates through the soil and superficial deposits can still run fairly quickly into the river. This, along with the roads and other impermeable surfaces, results in stormwater running rapidly into the river. These aspects combined with the low lying nature of the city put it at increased risk of fluvial flooding. In order to establish resilience to climate change, this is a key area where urban trees can benefit Cambridge, reducing both the amount of surface runoff, and the speed at which water enters the river system.

The trees within Cambridge's urban forest reduce runoff by an estimated 97,600m³ each year with an associated value of £153,00. This volume is equivalent to approximately 39 Olympic swimming pools of surface runoff being averted every single year. Figure 17 (below) shows the volumes and values for the ten most important genera for reducing runoff.

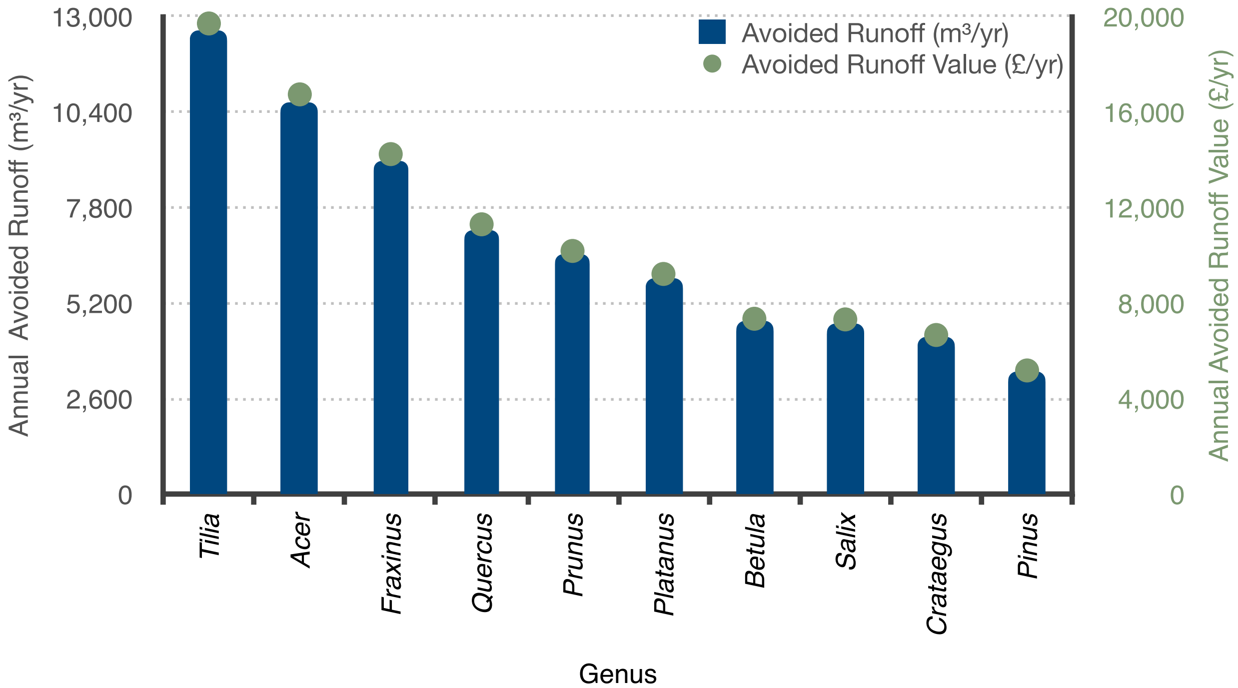


Figure 17: Annual Avoided Runoff and Associated Value by Top Ten Genera

The three genera providing the greatest avoided runoff are *Tilia* (lime), *Acer* (maple) and *Fraxinus* (ash). Of the *Tilia* genus, *Tilia platyphyllos* (large-leaved lime) intercepts the largest volume of precipitation for any single species, and is the most valuable species in terms of avoided runoff, intercepting 9,099 m³/yr worth an estimated £14,200.

4.2.5 Trees and Infrastructure

Trees in the urban forest have a unique role within the City of Cambridge. They affect the immediate surroundings of the 123,900 or so people who live and work in the area, providing benefits such as insulation, shade and clean oxygen. It is vital that these amenities are considered in planning and development to provide maximum benefits and ensure green infrastructure is incorporated where it is needed most.

The Tree & Design Action Group (TDAG) provide several guides and resources aimed at urban planners to aid the incorporation of green infrastructure within cities. The 'First Steps in Valuing Trees and Green Infrastructure' guide compiles information and advice about the use of economic valuation approaches for trees and green infrastructure, which tool or method to choose and how to get started. It outlines four general scenarios where valuing trees and green infrastructure deliver proven results. These include: achieving greater retention of existing green assets, securing more commensurate compensation when green assets are compromised or lost, enhancing design outcomes and how those outcomes are communicated, and, enabling evidence-based management (TDAG, 2019). TDAG's best practice guide, No Trees, No Future, emphasises the importance of considering trees in the earliest stages of design, and incorporating allowances for fully mature trees in the engineering from the outset. Although national and local policy now tends to encourage planting trees in urban areas, the way that new development is delivered often makes it impossible to accommodate larger trees. This is a huge issue, however there are ways to overcome these challenges. For example in high density developments there may be less room for tree roots and canopies, however space can often be found along boundaries, or adjacent to paths, or in areas of public open space (TDAG, 2010).

Whilst subsidence caused by trees is a risk perceived by many, it is actually far less common than often insinuated. One study in a London borough found that only 0.05% of its building stock was affected by tree-related insurance claims annually, and in areas where the subsoil is not shrinkable clay the risk is minor. These types of foundation movement are likely to increase — whether or not trees are present — as the effects of climate change increase. Trees can actually affect buildings in a positive way, providing energy saving, summertime cooling and providing oxygen and air pollution removal which saves on air filtration.

Energy effects

Trees can provide energy saving benefits to nearby buildings through shading buildings, providing evaporative cooling, and blocking winter winds. Trees tend to reduce building energy consumption in the summer months and can either increase or decrease building energy use in the winter months, depending on the degree of shading and angle of the tree in relation to the building. Where trees are able to reduce energy costs, properties typically require less heating/cooling, and therefore use less energy. In turn, this reduces the amount of carbon released by the traditional methods of energy production. Trees less than 3m tall or further than 18m away from buildings do not provide these benefits, and owing to the nature of the data collected it is difficult to quantify this for the whole of Cambridge, however the average carbon avoidance provided by a single tree for the surveyed trees is 3.34kg/yr. Figure 19 below shows the individual trees from the survey which produced the largest benefits to nearby buildings in terms of annual carbon avoidance.

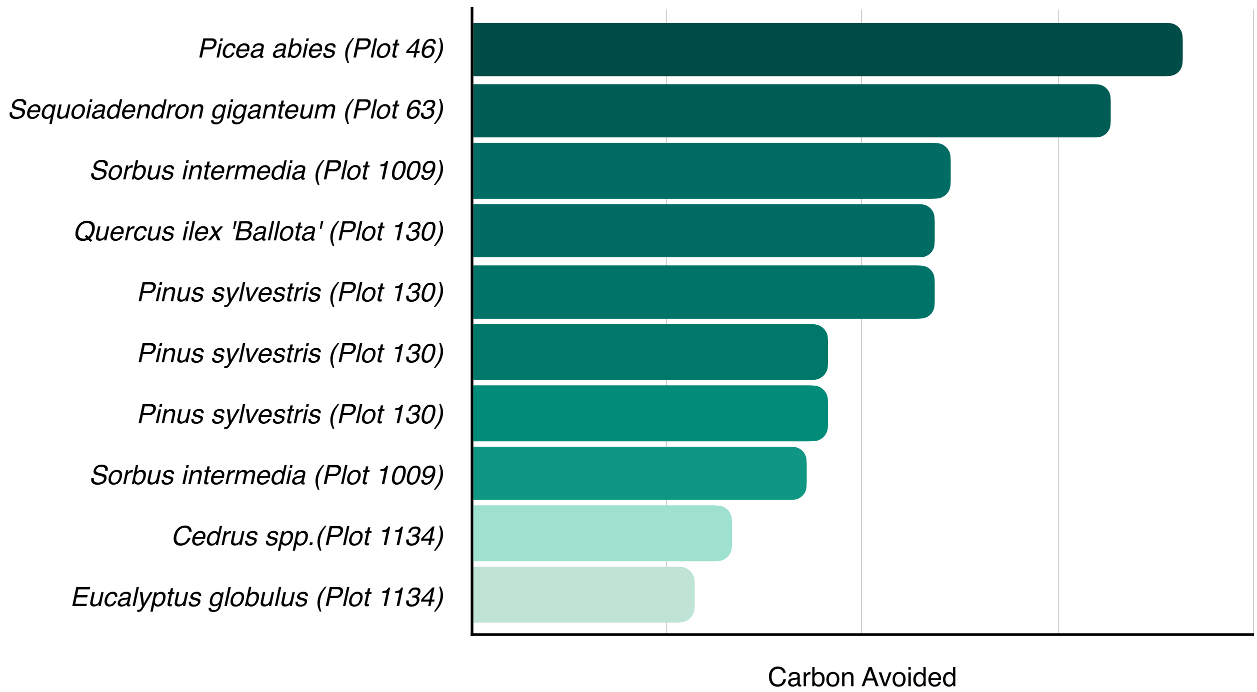


Figure 19: Carbon Avoided by Top 10 Individual Trees

Oxygen provision

The trees within Cambridge's urban forest provide an estimated 3,460 tonnes each year. The average human breathes about 9.5 tonnes of air in a year, of which about 740kg of oxygen is actually used (The Conscious Challenge, 2021). The trees in Cambridge therefore provide enough oxygen for 4,680 people each year-thats around 4% of Cambridge's population.

UV effects

UV radiation is emitted by the sun and while beneficial to humans in small doses, can have negative health effects when people are overexposed. Trees protect people from UV rays by providing shade, blocking sunlight from directly reaching the ground. Shade provision can help keep buildings and roads cool in the summer and reduce the heat island effect associated with cities (TDAG, 2010).

Table 7 (below) shows the effect Cambridge's trees have on UV factors. The effects in tree shade indicates the reduction in UV for a person entirely in the shade. The UV effects overall are for people in the vicinity of the tree but not always sheltered, for example walking down the street, sometimes in shade and sometimes exposed.

	Protection Factor	Reduction in UV Index	Percent reduction (%)
UV Effects in Tree Shade	1.881	1.518	39.47
UV Effects Overall	1.238	0.512	19.17

Table 7: UV Effects of Trees in Cambridge

Protection Factor is a value meant to capture the UV radiation blocking factor of trees and is comparable to the SPF factor of suncream. The UV index scale was developed by the World Health Organisation to more easily communicate daily levels of UV radiation and alert people to when protection from overexposure is needed most.

Reduction in UV Index is the change in UV index as a result of trees and calculated as unshaded UV index minus the shaded or overall UV index.

Percent reduction is the reduction in UV index expressed as a percent change as calculated as the reduction in UV index divided by unshaded UV index.

4.2.6 Recommendations for Ecosystem Services

It is recommended that in addition to the structure and composition recommendations:

7. A review is conducted of potential plantable space which could be mapped against local air quality,social indicators (e.g. index of multiple deprivation) and existing tree cover to identify and prioritise spaces and places where the addition of trees could help meet local need in the lowest performing wards.
8. Areas identified of most need are targeted to investigate on a site-by-site basis for tree planting suitability. The results should also be challenged by experts with local knowledge and experience as there may be 'barriers' to tree planting in the identified areas which will need to be addressed.
9. Species are selected that are appropriate to the site to maximise tree benefit delivery and realise the full site potential. Engaging with local communities can have a large impact on the successfulness of planting initiatives, and tree wardens can be a huge asset in achieving this.
10. Prioritise planting of large-leaved long lived species over smaller, ornamental species to maximise the ES provided (where appropriate).
11. Incorporate trees and green infrastructure from the outset of urban design and planning processes. Consideration of urban forests at this stage can help to protect these valuable resources and maintain balance between green spaces and grey infrastructure.
12. The development of any tree planting programme need to be sustainable and to be co-ordinated with other local stakeholders as part of a larger sustainable Urban Forest Masterplan for Cambridge. This should also include management strategies to help trees reach their full potential in the built environment.

4.3 Replacement Cost

In addition to estimating the environmental benefits provided by trees, Eco also provides a structural valuation. In the UK this is termed the 'Replacement Cost'. It must be stressed that the way in which this value is calculated means that it does not constitute a benefit provided by the trees. The valuation is a depreciated replacement cost, based on the Council of Tree and Landscape Appraisers (CTLA) formulae (Hollis, 2007).

Replacement Cost is intended to provide a useful management tool, as it is able to value what it might cost to replace any or all of the trees (taking account of species suitability, depreciation and other economic considerations) should they become damaged or diseased for instance. The replacement costs for the ten most valuable tree species are shown in Figure 20 (below). **The total value of all trees in the study area, as estimated by Eco, currently stands at over £172 million.**

The three most valuable genera are *Tilia* (lime), *Quercus* (oak) and *Salix* (willow), These three genera alone have a replacement cost of £53 million (31%) of the total replacement cost of the trees in Cambridge's urban forest.

The species *Tilia x europaea* (large-leaved lime) alone accounts for 7.4% of the total replacement cost. A full list of trees with the associated replacement cost is given in Appendix III.

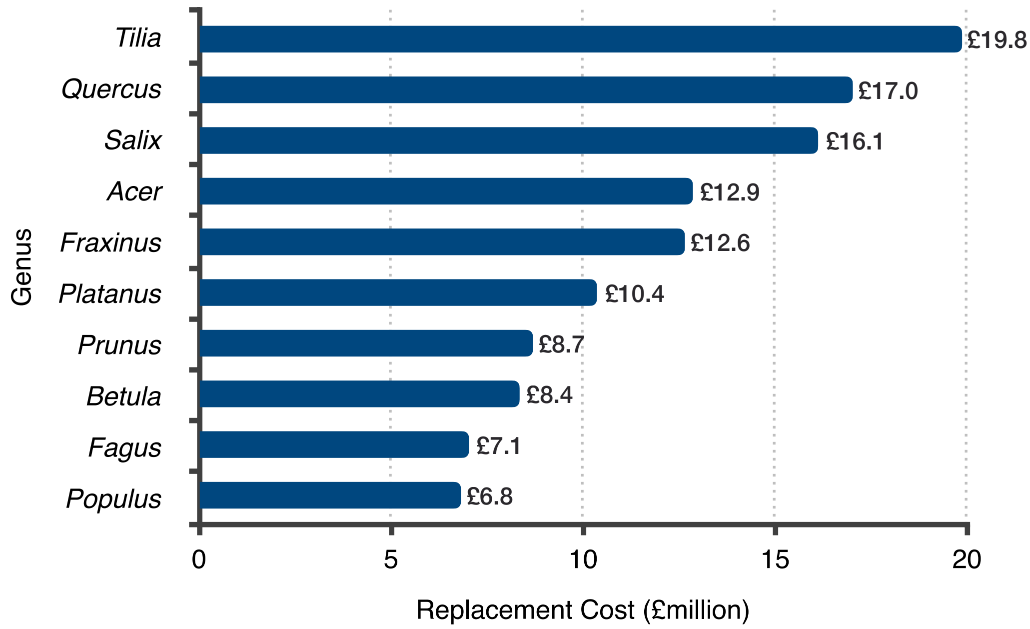


Figure 20: Replacement Cost for Top Ten Tree Genera in Cambridge

4.4 CAVAT - The Amenity Value of Trees

Capital Asset Valuation for Amenity Trees (CAVAT) is a method developed in the UK to provide a value for the public amenity that trees provide. The Council of Tree and Landscape Appraisers (CTLA) valuation method does not take into account the health or amenity value of trees, and is a management tool rather than a benefit valuation.

Particular differences to the CTLA valuation include the Community Tree Index (CTI) value, which adjusts the CAVAT assessment to take account of the greater benefits of trees in areas of higher population density, using official population figures. CAVAT allows the value of Cambridge's trees to include a social dimension by valuing the visual accessibility and prominence within the overall urban forest.

For the urban forest of Cambridge, the estimated total public amenity asset value is in excess of £1.03 billion!

It should be noted that due to the nature of street trees and the CAVAT methodology, local factors and management choices could not be taken into account as part of this study. The value should reflect the reality that street trees have to be managed for safety. They are frequently crown lifted and reduced (to a greater or lesser extent) and are generally growing in conditions of greater stress than their open grown counterparts. As a result, they may have a significantly reduced functionality under the CAVAT system.

Some assumptions of Life Expectancy (LE) were made based on tree species and condition, as this was not collected in all surveys.

Genus	CAVAT Value	Percent of Total Population	Replacement Cost
Quercus	£129,100,000	4.5%	£17,000,000
Tilia	£100,600,000	6.1%	£19,800,000
Acer	£89,400,000	10.6%	£12,900,000
Salix	£87,500,000	2.1%	£16,100,000
Platanus	£86,500,000	2.6%	£10,400,000
Betula	£47,000,000	5.9%	£8,400,000
Fraxinus	£43,700,000	5.2%	£12,600,000
Prunus	£41,000,000	11.1%	£8,700,000
Paulownia	£39,200,000	0.2%	£5,900,000
Pinus	£36,400,000	2.1%	£5,500,000
All Other Species	**£334,600,000**	**49.6%**	**£917,600,000**
Total	**£1,034,900,000**	**100%**	**£172,000,000**

Table 8: The ten genera with the highest CAVAT valuation.

4.5 Summary by Ward

For this survey, the number of plots surveyed did not allow for pre-stratification. Instead, values were post-stratified to establish ES values for each ward. These values are an estimate based on the values extrapolated by Eco from the surveyed plots. Using the total number of trees, the number of trees in each ward and the ward areas, the ES values have been scaled to provide an approximation of the services provided by trees in each ward. Pollution removal cannot be scaled in this way due to the way the Eco outputs are configured and therefore they have been omitted. As this data is a scaled approximation, ES totals from this table are similar but not identical to the totals in prior sections.

Ward Name	Carbon Storage (Tonnes)	Carbon Storage (£)	Carbon Sequestration (Tonnes)	Carbon Sequestration (£)	Avoided runoff (m^3/yr)	Avoided runoff (£/yr)
Abbey	5,620	£1,440,000	193	£49,700	7,920	£12,400
Arbury	2,480	£640,000	86	£21,900	3,500	£5,500
Castle	4,530	£1,160,000	156	£40,000	6,380	£10,000
Cherry Hinton	5,170	£1,330,000	178	£45,700	7,290	£11,400
Coleridge	3,080	£790,000	106	£27,200	4,330	£6,800
East Chesterton	4,400	£1,130,000	152	£38,900	6,200	£9,700
King's Hedges	2,510	£640,000	87	£22,200	3,540	£5,500
Market	2,970	£760,000	102	£26,300	4,190	£6,600
Newnham	7,420	£1,910,000	256	£65,600	10,460	£16,400
Petersfield	1,670	£430,000	57	£14,800	2,350	£3,700
Queen Edith's	8,660	£2,220,000	298	£76,500	12,200	£19,100
Romsey	2,400	£620,000	83	£21,200	3,380	£5,300
Trumpington	12,210	£3,140,000	421	£107,900	17,210	£26,900
West Chesterton	2,510	£640,000	86	£22,200	3,530	£5,500

Table 9: Summary of estimated ecosystem services by ward.

5.0 Conclusions

The tree population within Cambridge's urban forest has a good species diversity, with 105 species identified.

The trees within **Cambridge's urban forest provide a valuable benefit of over £1,670,000 in ecosystem services each year.**

In terms of structural diversity, *Crataegus* is the most common genus (12.5% of the population), followed by *Prunus* (11.1%) and *Acer* (10.6%). Larger-growing trees are important because they can provide greater canopy cover and therefore ecosystem service provision. They also tend to have higher amenity values than their smaller counterparts.

The most common species is *Crataegus monogyna* (hawthorn) accounting for 11.1% of the total population, which is significantly more than any other species, and indicates a reliance on this species which may reduce the resilience of Cambridge's urban forest. The top 10 most common species account for 44% of all trees, store 27% of the total amount of carbon, sequester 558 tonnes of carbon each year and reduce the city's surface runoff by 35,200m^3 each year worth £55,000 in avoided sewerage charges. Like many urban areas, Cambridge's urban forest would benefit from having a greater proportion of larger trees, and less reliance on a few key species for ES delivery by increasing the diversity of newly planted trees.

The values presented in this study should be seen as conservative estimates, only a proportion of the total potential benefits have been evaluated. Trees confer many benefits which have not been valued as part of this report, such as contributions to our health and well-being, reducing urban temperatures, providing amenity value and habitats for wildlife (Davies *et al*, 2017).

The extent of these benefits needs to be recognised. Strategies and policies that will conserve this important resource (through education for example) would be one way to address this. Targets to increase canopy cover including planting larger trees, protecting large and veteran trees and, where possible, continue to diversify the urban forest through planting climate adaptable species should also be investigated through the production of an 'Urban Forest Masterplan'. Introducing and enforcing policies regarding the incorporation of green infrastructure in planning and design would go a long way to helping ensure trees reach their full potential in the urban environment.

As the amount of healthy leaf area equates directly to the provision of benefits, consistent and considered management of the tree stock is important to ensure canopy cover levels continue to be maintained or increased. New tree planting can contribute to the growth of canopy cover. However, the most effective strategy for increasing average tree size and the extent of tree canopy is to adopt a management approach that enables a sustainable, healthy, age and species diverse tree population. This means that protecting existing tree stock is vital, and planning for tree growth must be taken into account before planting, to ensure the trees can remain a long-term, nature based solution to the challenges ahead.

Climate change could affect the tree stock in Cambridge's urban forest in a variety of ways and there are great uncertainties about how this may manifest. Some species may be less able to survive under new climatic conditions. New climatic conditions may also allow new and present pests and diseases to become prevalent or to change their behaviours. Further studies into this area would be useful in informing any long-term tree strategies or Urban Forest Masterplans, that carefully consider species selection.

The challenge now is to ensure that policy makers and practitioners take full account of Cambridge's trees in decision making. Not only are trees a valuable functional component of our landscape, they also make a significant contribution to people's quality of life. Incorporating the urban forest and green infrastructure in planning and design from the outset is vital to ensuring that Cambridge can make the most of its space and maximise the benefits of trees for generations to come.

6.1 Appendix I. Relative Tree Effects

The urban forest of Cambridge provides benefits that include carbon storage and sequestration, air pollutant removal and reducing surface runoff. To estimate the relative value of these benefits, tree benefits were compared to estimates of average carbon emissions and average family car emissions. These figures should be treated as a guideline only as they are largely based on US values.

Carbon storage is equivalent to:

- Amount of carbon emitted in Cambridge in 54 days
- Annual carbon (C) emissions from 68,600 automobiles
- Annual C emissions from 28,100 single-family houses

Nitrogen dioxide removal is equivalent to:

- Annual nitrogen dioxide emissions from 2,650 automobiles
- Annual nitrogen dioxide emissions from 1,190 single-family houses

Sulphur dioxide removal is equivalent to:

- Annual sulphur dioxide emissions from 111 automobiles
- Annual sulphur dioxide emissions from 0 single-family houses

Annual carbon sequestration is equivalent to:

- Amount of carbon emitted in Cambridge in 1.3 days
- Annual C emissions from 1,600 automobiles
- Annual C emissions from 700 single-family houses

Municipal carbon emissions are based on 2010 U.S. per capita carbon emissions (Carbon Dioxide Information Analysis Center 2010). Per capita emissions were multiplied by city population to estimate total city carbon emissions.

Light duty vehicle emission rates (g/mi) for CO, NO_x, VOCs, PM, SO_2 for 2010 (Bureau of Transportation Statistics 2010; Heirigs et al 2004), PM2.5 for 2011-2015 (California Air Resources Board 2013), and CO_2 for 2011 (U.S. Environmental Protection Agency 2010) were multiplied by average miles driven per vehicle in 2011 (Federal Highway Administration 2013) to determine average emissions per vehicle.

Household emissions are based on average electricity kWh usage, natural gas Btu usage, fuel oil Btu usage, kerosene Btu usage, LPG Btu usage, and wood Btu usage per household in 2009 (Energy Information Administration 2013; Energy Information Administration 2014)

- CO_2, SO_2, and NO_x power plant emission per KWh are from Leonardo Academy 2011. CO emission per kWh assumes 1/3 of one percent of C emissions is CO based on Energy Information Administration 1994. PM emission per kWh from Layton 2004.
- CO_2, NO_x, SO_2, and CO emission per Btu for natural gas, propane and butane (average used to represent LPG), Fuel #4 and #6 (average used to represent fuel oil and kerosene) from Leonardo Academy 2011.
- CO_2 emissions per Btu of wood from Energy Information Administration 2014.
- CO, NO_x and SO_2 emission per Btu based on total emissions and wood burning (tons) from (British Columbia Ministry 2005; Georgia Forestry Commission 2009).

Oxygen production figures are based on the total oxygen produced by the trees within Cambridge's urban forest divided by the average intake of oxygen for each person per year - https://ntrs.nasa.gov/search.jsp?R=20060005209

6.2 Appendix II. Species Dominance Ranking List

Species	Percent Population	Percent Leaf Area	Dominance Value
Crataegus monogyna	11.11%	3.09%	14.2
Acer campestre	6.62%	6.05%	12.7
Tilia platyphyllos	2.13%	9.32%	11.4
Acer pseudoplatanus	3.55%	3.97%	7.5
Fraxinus excelsior	1.66%	5.27%	6.9
Platanus	1.89%	5.04%	6.9
Prunus avium	4.02%	2.73%	6.7
Fraxinus	2.60%	3.57%	6.2
Ulmus procera	4.49%	1.60%	6.1
Tilia x europaea	2.60%	2.67%	5.3
Betula pendula	3.55%	1.38%	4.9
Prunus padus	3.31%	1.64%	4.9
Quercus/live ilex 'Ballota'	0.71%	3.77%	4.5
Quercus robur	1.66%	1.90%	3.6
Pinus sylvestris	1.42%	2.04%	3.5
Betula	1.66%	1.61%	3.3
Ailanthus altissima	2.13%	1.10%	3.2
Salix alba	0.95%	2.18%	3.1
Crataegus	1.42%	1.27%	2.7
Juglans	0.95%	1.68%	2.6
Populus tremula	0.95%	1.54%	2.5
Thuja plicata	1.66%	0.88%	2.5
Corylus colurna	0.71%	1.67%	2.4
Prunus x orthosepala	0.95%	1.44%	2.4
Fagus	0.71%	1.55%	2.3
Sorbus intermedia	0.71%	1.47%	2.2
Betula papyrifera	0.47%	1.63%	2.1
Carpinus betulus	1.18%	0.57%	1.8
Robinia pseudoacacia	0.95%	0.88%	1.8
Zelkova carpinifolia	0.47%	1.38%	1.8
Cedrus libani	0.24%	1.48%	1.7
Cupressocyparis leylandii	1.42%	0.27%	1.7
Platanus occidentalis	0.71%	0.99%	1.7

Species	Percent Population	Percent Leaf Area	Dominance Value
Populus nigra	1.42%	0.28%	1.7
Quercus	0.95%	0.72%	1.7
Salix babylonica	0.24%	1.50%	1.7
Cedrus	0.24%	1.32%	1.6
Picea abies	0.47%	1.06%	1.5
Fagus sylvatica	0.95%	0.49%	1.4
Quercus petraea	0.95%	0.48%	1.4
Aesculus hippocastanum	0.71%	0.64%	1.3
Ilex aquifolium	1.18%	0.09%	1.3
Corylus avellana	0.47%	0.69%	1.2
Pinus strobus	0.24%	0.98%	1.2
Prunus spinosa	0.95%	0.24%	1.2
Salix x chrysocoma	0.24%	0.93%	1.2
Tilia cordata	0.95%	0.29%	1.2
Paulownia tomentosa	0.24%	0.86%	1.1
Populus nigra v. italica	0.24%	0.84%	1.1
Tilia tomentosa	0.47%	0.62%	1.1
Acacia	0.24%	0.81%	1.0
Alnus	0.71%	0.31%	1.0
Sophora japonica	0.71%	0.27%	1.0
Alnus glutinosa	0.71%	0.23%	0.9
Amelasorbus	0.24%	0.66%	0.9
Laburnum anagyroides	0.71%	0.16%	0.9
Acer	0.24%	0.60%	0.8
Magnolia	0.47%	0.31%	0.8
Malus	0.71%	0.06%	0.8
Prunus	0.71%	0.07%	0.8
Prunus cerasifera	0.47%	0.32%	0.8
Quercus palustris	0.24%	0.52%	0.8
Sequoiadendron giganteum	0.24%	0.54%	0.8
Taxus baccata	0.71%	0.10%	0.8
Eucalyptus globulus	0.24%	0.43%	0.7
Fraxinus excelsior 'Pendula'	0.47%	0.24%	0.7
Laurus nobilis	0.47%	0.25%	0.7

Species	Percent Population	Percent Leaf Area	Dominance Value
Sambucus nigra	0.71%	0.02%	0.7
Abies	0.47%	0.12%	0.6
Acer negundo	0.24%	0.34%	0.6
Azara microphylla	0.24%	0.36%	0.6
Cupressus	0.47%	0.11%	0.6
Laburnum	0.47%	0.09%	0.6
Pinus patula	0.24%	0.33%	0.6
Prunus alabamensis	0.47%	0.08%	0.6
Salix	0.47%	0.17%	0.6
Sorbus aucuparia	0.47%	0.08%	0.6
Corylus	0.47%	0.06%	0.5
Euonymus	0.47%	0.02%	0.5
Fagus orientalis	0.24%	0.27%	0.5
Picea omorika	0.24%	0.30%	0.5
Sorbus torminalis	0.24%	0.28%	0.5
Betula utilis	0.24%	0.19%	0.4
Fraxinus angustifolia	0.24%	0.21%	0.4
Ginkgo biloba	0.24%	0.12%	0.4
Magnolia grandiflora	0.24%	0.18%	0.4
Prunus pissardii	0.24%	0.15%	0.4
Pyrus salicifolia	0.24%	0.14%	0.4
Robinia pseudoacacia 'Frisia'	0.24%	0.17%	0.4
Sorbus latifolia	0.24%	0.14%	0.4
Abies nordmanniana	0.24%	0.09%	0.3
Chamaecyparis lawsoniana	0.24%	0.03%	0.3
Ficus	0.24%	0.09%	0.3
Fraxinus quadrangulata	0.24%	0.03%	0.3
Ilex	0.24%	0.04%	0.3
Magnolia x soulangiana 'Galaxy'	0.24%	0.06%	0.3
Malus sylvestris	0.24%	0.05%	0.3
Malus tschonoskii	0.24%	0.03%	0.3
Photinia glabra	0.24%	0.02%	0.3
Pinus nigra	0.24%	0.04%	0.3
Salix caprea	0.24%	0.02%	0.3

Species	Percent Population	Percent Leaf Area	Dominance Value
Sorbus	0.24%	0.02%	0.3
Laburnum alpinum	0.24%	0.00%	0.2
Malus ioensis 'Plena'	0.24%	0.00%	0.2
Rhododendron	0.24%	0.00%	0.2

Table 9: Dominance Ranking by Species

6.3 Appendix III. Replacement Cost by Species

Species	Trees	Carbon Storage (tonnes)	Gross Carbon Seq (tonnes/ Yr)	Avoided Runoff (m³/Yr)	Pollution Removal (tonnes/ Yr)	Replacement Cost (£)
Tilia platyphyllos	4,518	2,644	62	9,099	3.9	£12,766,888
Quercus/live ilex 'Ballota'	1,506	4,114	24	3,684	1.6	£12,579,001
Platanus	4,016	2,928	99	4,922	2.1	£7,274,655
Acer campestre	14,055	4,090	37	5,904	2.6	£6,957,298
Tilia x europaea	5,521	3,824	156	2,603	1.1	£6,554,730
Fraxinus	5,521	4,409	41	3,484	1.5	£6,550,987
Salix x chrysocoma	502	3,765	8	905	0.4	£6,419,691
Paulownia tomentosa	502	1,092	23	837	0.4	£5,947,728
Fagus	1,506	4,125	31	1,510	0.7	£5,746,963
Fraxinus excelsior	3,514	2,308	43	5,143	2.2	£5,444,166
Betula	3,514	3,339	103	1,568	0.7	£4,296,206
Cupressocyparis leylandii	3,012	4,206	118	262	0.1	£4,190,103
Salix	1,004	2,002	90	164	0.1	£4,123,647
Acer pseudoplatanus	7,529	2,236	80	3,877	1.7	£4,008,606
Populus nigra v. italica	502	3,765	8	820	0.4	£3,937,410
Juglans	2,008	1,437	9	1,643	0.7	£3,576,099
Salix alba	2,008	3,025	85	2,124	0.9	£3,134,965
Platanus occidentalis	1,506	523	30	969	0.4	£3,118,620
Betula papyrifera	1,004	1,077	62	1,589	0.7	£2,746,396
Sorbus intermedia	1,506	1,508	2	1,436	0.6	£2,708,259
Cedrus libani	502	1,362	1	1,444	0.6	£2,661,681
Prunus avium	8,533	1,092	47	2,666	1.2	£2,616,678
Pinus sylvestris	3,012	500	29	1,993	0.9	£2,583,418
Pinus strobus	502	363	17	959	0.4	£2,555,411
Cedrus	502	1,250	24	1,289	0.6	£2,418,484
Salix babylonica	502	1,877	5	1,467	0.6	£2,400,943
Thuja plicata	3,514	485	7	858	0.4	£2,371,324
Prunus x orthosepala	2,008	1,096	5	1,404	0.6	£2,166,685
Robinia pseudoacacia	2,008	811	29	855	0.4	£2,108,407

Species	Trees	Carbon Storage (tonnes)	Gross Carbon Seq (tonnes/ Yr)	Avoided Runoff (m³/Yr)	Pollution Removal (tonnes/ Yr)	Replacement Cost (£)
Prunus padus	7,027	1,938	13	1,597	0.7	£2,088,051
Crataegus monogyna	23,592	2,135	11	3,015	1.3	£1,964,231
Populus tremula	2,008	953	32	1,504	0.7	£1,905,860
Quercus robur	3,514	1,293	59	1,859	0.8	£1,850,967
Sequoiadendron giganteum	502	1,004	20	527	0.2	£1,658,857
Acer	502	874	1	587	0.3	£1,460,236
Alnus glutinosa	1,506	209	1	223	0.1	£1,425,798
Quercus palustris	502	430	12	505	0.2	£1,291,003
Betula pendula	7,529	421	53	1,351	0.6	£1,249,074
Fagus sylvatica	2,008	570	26	483	0.2	£1,235,062
Amelasorbus	502	697	1	646	0.3	£1,227,432
Zelkova carpinifolia	1,004	384	22	1,343	0.6	£1,197,930
Crataegus	3,012	422	3	1,244	0.5	£1,152,974
Picea abies	1,004	476	13	1,031	0.5	£1,030,743
Populus nigra	3,012	261	30	276	0.1	£945,484
Picea omorika	502	776	32	295	0.1	£916,859
Corylus colurna	1,506	482	31	1,632	0.7	£862,948
Prunus cerasifera	1,004	871	15	314	0.1	£829,409
Azara microphylla	502	615	0	351	0.2	£819,317
Quercus	2,008	466	12	699	0.3	£793,783
Ilex aquifolium	2,510	167	11	90	0.0	£697,083
Ailanthus altissima	4,518	315	35	1,074	0.5	£608,105
Sorbus torminalis	502	163	4	273	0.1	£552,600
Ulmus procera	9,537	1,374	58	1,565	0.7	£547,667
Abies nordmanniana	502	324	12	86	0.0	£539,326
Eucalyptus globulus	502	57	2	419	0.2	£535,833
Fraxinus excelsior 'Pendula'	1,004	556	14	236	0.1	£532,820
Prunus alabamensis	1,004	427	7	81	0.0	£496,543
Quercus petraea	2,008	414	8	472	0.2	£484,315
Acer negundo	502	100	10	328	0.1	£440,540
Laburnum anagyroides	1,506	258	6	161	0.1	£374,465

Species	Trees	Carbon Storage (tonnes)	Gross Carbon Seq (tonnes/ Yr)	Avoided Runoff (m³/Yr)	Pollution Removal (tonnes/ Yr)	Replacement Cost (£)
Magnolia	1,004	123	13	302	0.1	£373,510
Sorbus latifolia	502	183	2	137	0.1	£366,049
Pinus patula	502	62	5	322	0.1	£348,775
Tilia cordata	2,008	203	7	282	0.1	£324,237
Acacia	502	48	0	788	0.3	£311,924
Malus	1,506	120	11	55	0.0	£284,274
Abies	1,004	224	16	116	0.1	£274,556
Prunus pissardii	502	125	7	143	0.1	£270,873
Corylus avellana	1,004	93	6	676	0.3	£268,515
Carpinus betulus	2,510	93	10	560	0.2	£250,802
Robinia pseudoacacia 'Frisia'	502	92	0	164	0.1	£226,363
Laurus nobilis	1,004	202	17	248	0.1	£222,063
Ginkgo biloba	502	60	1	114	0.1	£216,075
Taxus baccata	1,506	67	4	98	0.0	£193,129
Tilia tomentosa	1,004	51	6	607	0.3	£190,056
Corylus	1,004	173	10	58	0.0	£188,019
Malus sylvestris	502	81	5	47	0.0	£181,069
Laburnum	1,004	114	0	87	0.0	£154,380
Alnus	1,506	146	4	298	0.1	£149,947
Magnolia grandiflora	502	48	5	173	0.1	£138,709
Prunus spinosa	2,008	63	6	238	0.1	£103,509
Aesculus hippocastanum	1,506	147	7	625	0.3	£99,803
Prunus	1,506	36	8	64	0.0	£94,914
Cupressus	1,004	221	15	111	0.1	£87,555
Pyrus salicifolia	502	51	2	133	0.1	£84,902
Fagus orientalis	502	83	0	266	0.1	£73,882
Sambucus nigra	1,506	61	0	19	0.0	£72,469
Sophora japonica	1,506	34	3	263	0.1	£70,921
Salix caprea	502	30	2	16	0.0	£68,770
Sorbus aucuparia	1,004	28	6	79	0.0	£68,588
Betula utilis	502	38	3	184	0.1	£64,735
Fraxinus angustifolia	502	22	3	201	0.1	£64,229

Species	Trees	Carbon Storage (tonnes)	Gross Carbon Seq (tonnes/ Yr)	Avoided Runoff (m^3/Yr)	Pollution Removal (tonnes/ Yr)	Replacement Cost (£)
Euonymus	1,004	12	4	19	0.0	£56,116
Malus tschonoskii	502	24	4	33	0.0	£55,320
Ficus	502	38	5	86	0.0	£43,184
Ilex	502	26	4	42	0.0	£41,602
Magnolia x soulangiana 'Galaxy'	502	17	3	58	0.0	£41,070
Pinus nigra	502	3	1	37	0.0	£37,646
Sorbus	502	12	0	24	0.0	£34,634
Photinia glabra	502	8	2	20	0.0	£33,205
Malus ioensis 'Plena'	502	4	1	4	0.0	£30,870
Fraxinus quadrangulata	502	7	1	33	0.0	£28,988
Chamaecyparis lawsoniana	502	10	2	32	0.0	£24,846
Rhododendron	502	19	2	4	0.0	£22,690
Laburnum alpinum	502	9	0	3	0.0	£7,951
Total	212,336	88,000	2,042	97,612	42.2	£172,026,489.04

Table 10: Replacement Cost by Species

6.4 Appendix IV. Pests and Disease

Acute Oak Decline

Acute oak decline (AOD) mainly affects mature trees (>50 years old) of both native oak species (*Quercus robur* and *Q. petraea*), but symptoms have also been identified on younger oaks and additional species, including *Q. cerris* and *Q. fabri.* Some affected trees can die in as little as 4-6 years after symptoms have developed. Over the past few years, the reported incidents of stem bleeding and exit holes of the associated beetle *Agrilus bigatatus*, indicating potential AOD infection, have been increasing. The condition appears to be most prevalent in the Midlands and the South East of England, although is spreading west. There are confirmed cases of acute oak decline on the Welsh/English border and in South East Wales.

Asian Longhorn Beetle

The Asian longhorn beetle (*Anoplophlora glabripennis*) is a major pest in China, Japan and Korea, where it kills many broadleaved species. There are established populations of Asian longhorn beetle (ALB) in parts of North America and have been outbreaks in Europe too. Where the damage to street trees is high, felling, sanitation and quarantine are the only viable management options.

In March 2012 an ALB outbreak was found in Maidstone, Kent. The Forestry Commission and Fera removed more than 2,000 trees from the area to contain the outbreak. No further outbreaks have been reported in the UK. Modelled climatic suitability for outbreaks based on outbreak data from China and the USA (MacLeod, Evans & Baker, 2002) suggest that Cambridge may be vulnerable to ALB.

The known host tree and shrub species include:

- *Acer spp*. (maples and sycamores)
- *Aesculus spp.* (horse chestnut)
- *Albizia julibrissin* (Mimosa silk tree)
- *Alnus spp.* (alder)
- *Betula spp.* (birch)
- *Carpinus spp.* (hornbeam)
- *Cercidiphyllum japonicum* (Katsura tree)
- *Corylus spp.* (hazel)
- *Fagus spp.* (beech)

- *Fraxinus spp.* (ash)
- *Koelreuteria paniculata* (Golden rain tree)
- *Malus spp.* (apple)
- *Platanus spp*. (plane)
- *Populus spp*. (poplar)
- *Prunus spp*. (cherry, plum)
- *Pyrus spp.* (pear)
- *Robinia pseudoacacia* (false acacia/black locust)
- *Salix spp.* (willow, sallow)
- *Sorbus spp.* (rowan, whitebeam etc)
- *Styphnolobium japonicum* (Japanese pagoda tree)
- *Quercus palustris* (American pin oak)
- *Quercus rubra* (North American red oak)
- *Ulmus spp.* (elm).

Bronze Birch Borer

The Bronze birch borer (*Agrilus anxius*) is a wood-boring beetle that feeds on the inner bark and cambium of birch trees. The disruption to water and nutrient flow that occurs as a result means that trees can die within a few years after symptoms appear. At current, the Bronze birch borer is present across North America, including the United States, where it is native, and Canada. In these locations, the borer has caused extensive mortality of *Betula spp.* planted as street and ornamental trees in towns and cities, due to its ability to colonise most birch species and cultivars.

Canker stain of plane

Canker stain of plane, also known as plane tree wilt, is caused by the fungus *Ceratocystis platani.* It poses a significant threat to *Platanus spp*., because of the large number of plane trees (particularly mature trees) planted within towns and cities across the UK. Canker stain of plane affects the xylem of the tree, resulting in a pronounced decline in tree condition and eventually leading to tree death. It is not currently present in the UK, but it is found in several countries across Europe, such as France, Greece, Italy and Albania.

Chalara Dieback of Ash

Ash dieback, caused by the fungus *Hymenoscyphus fraxineus*, is a highly destructive disease of ash trees, including *Fraxinus excelsior*, *F. excelsior 'Pendula'* and *F. angustifolia.* Young trees are particularly susceptible and can be killed within one growing season of symptoms becoming visible. Older trees can take longer to succumb but can die from the infection or secondary pathogens (e.g. *Armillaria*) after several seasons. *H. fraxineus* was first recorded in the UK in 2012 in Buckinghamshire and has now been widely reported in most areas across the UK.

Citrus Longhorn Beetle

The citrus longhorn beetle (A*noplophora chinensis*) is a wood-boring beetle, which naturally ranges across China, Japan, the Korean Peninsula and South-East Asia. The beetle feeds on the vascular systems of the trunk, the foliage and young bark, depending on its life stage. Their tunnels can weaken trees, increasing susceptibility to secondary pathogens. The citrus longhorn beetle can feed on and attack a substantial range of trees (see below) and therefore could have a significant impact on UK urban forests, as well as being a substantial economic threat.

The known host tree and shrub species include:
- *Acer spp.* (maples and sycamores)
- *Aesculus spp*. (horse chestnut)
- *Alnus spp*. (alder)
- *Betula spp*. (birch)
- *Carpinus spp*. (hornbeam)
- *Cornus spp*. (dogwood)
- *Corylus spp*. (hazel)
- *Crataegus spp*. (Hawthorn)
- *Cryptomeria japonica*
- *Fagus spp*. (beech)
- *Ficus spp*.
- *Juglans* (Walnut)
- *Lagerstroemia indica*
- *Litchi chinensis*
- *Malus spp.* (apple)
- *Melia azedarach*
- *Morus spp.*
- *Platanus spp.* (plane)
- *Populus spp.* (poplar)

- *Prunus spp*. (cherry, plum)
- *Pyrus spp.* (pear)
- *Salix spp.* (willow, sallow)
- *Ulmus spp.* (elm).

Dutch Elm Disease

Dutch elm disease, caused by two fungi: *Ophiostoma novo-ulmi* and *Ophiostoma ulmi,* has caused widespread destruction of the *Ulmus* genus since it was accidentally introduced into the UK in the 1960s. The disease is present in all parts of the UK. Infection by the fungi, which is spread between trees by elm bark beetles, results in the tree reacting by plugging its own xylem tissue, preventing water and nutrient travel up through the tree trunk and starving the tree. English elm (*Ulmus procera*) has been worst affected by Dutch elm disease because the elm bark beetles which spread the fungus prefer this species as a food source over other elm species.

Eight-toothed Spruce Bark Beetle

The eight-toothed spruce bark beetle (*Ips typographus*) can be found across Europe, China, Japan, North and South Korea and Tajikistan. Whilst they tend to prefer to attack weakened, stressed or dead trees, the beetles can also move on to healthy trees, meaning that this could pose a significant threat to UK timber industries in particular. One outbreak occurred in Kent in 2018 and is still being eradicated. Species that are susceptible to infestation include:

- *Abies spp.* (Fir)
- *Picea spp*. (Spruce)
- *Pinus spp*. (Pine)
- *Pseudotsuga spp.*
- *Larix spp.* (Larch)

Elm zigzag sawfly

The elm zigzag sawfly (*Aproceros leucopoda*) is a pest of elm trees, which feeds on their leaves. Elm zigzag sawfly is native to Japan and parts of China, and was first identified in the UK in 2017. In some parts of Europe, there has been severe defoliation as a result of elm zigzag sawfly, as much as 98% in some instances (Forest Research, 2021). However, this defoliation rate can vary, with some defoliation rates at only 1-2%. With the UK's elm population still recovering from the impact of Dutch elm disease, the spread of elm zigzag sawfly could have affect the vitality of remaining elm trees, and affect our native insect population by competing for elm as a food source.

Emerald Ash Borer

Emerald ash borer (EAB) (*Agrilus planipennis*) is likely to have a major impact on our already vulnerable ash population in the UK if established. There is no evidence to date that EAB is present in the UK, but the increase in global movement of imported wood and wood packaging heightens the risk of its accidental introduction. EAB is present in Russia and Ukraine and is moving West and South at a rate of 30-40 km per year, perhaps aided by vehicles (Straw *et al.*, 2013). EAB has had a devastating effect in the USA due to its accidental introduction and could add to pressures already imposed on ash trees from diseases such as Chalara dieback of ash.

Horse Chestnut Bleeding Canker

Horse chestnut bleeding canker is mostly caused by the bacterium *Pseudomonas syringae pathovar aesculi*, and has become widespread across Great Britain since it was first reported in the 1970s. A survey undertaken in 2007 (Forestry Commission) showed that in the East of England, 59% of horse chestnuts within urban areas had symptoms of bleeding canker, and that stem bleeds and cracking on branches were the most common symptoms at 70% and 78% respectively.

Oak Processionary Moth

Oak processionary moth (OPM) (*Thaumetopoea processionea*) was first accidentally introduced to Britain in 2005 and now there are established OPM populations in most of Greater London and in some surrounding counties. It is thought that OPM has been spread through imported nursery trees and it has been estimated that OPM could survive and breed in much of England and Wales. The caterpillars cause serious defoliation of oak trees, their principal host, which can leave them more vulnerable to other stresses. The caterpillars have urticating (irritating) hairs that can cause serious irritation to the skin, eyes and bronchial tubes of humans and animals. They are considered a significant human health problem when populations reach outbreak proportions, such as those in the Netherlands and Belgium in recent years. Whilst the outbreak in London is beyond eradicating, the rest of the UK maintains its European Union Protected Zone status (PZ) and restrictions on moving oak trees are in place to minimise the risk of further spread.

Phytophthora lateralis

The water mould *Phytophthora lateralis* attacks mostly Lawson cypress, but some other species including Western red cedar and Douglas fir. *P. lateralis* can disrupt water and nutrient flow by attacking the base of the tree and girdling the phloem. It is present in all four countries across the UK, as well as in parts of Europe and the west coast of the USA. Because *P. lateralis* usually kills the trees it infects, this could have a significant impact on trees in urban environments, as species such as Lawson cypress are a common choice for amenity planting.

Pine Processionary moth

The pine processionary moth (*Thaumetopoea pityocampa*) is similar to its close relative the oak processionary moth, in that it can cause severe defoliation and present a human health hazard due to its urticating hairs. The moths prefer to attack *Pinus spp.* with some species more susceptible, such as Scots pine and Austrian pine. The moth has also been recorded on Atlas cedar and European larch. The pine processionary moth is not currently present in the UK, but there have been interceptions in southern England previously.

Xylella fastidiosa

Xylella fastidiosa is a bacterium that has the potential to cause significant damage to a range of broadleaf trees and commercially grown plants. The bacterium has been found in Italy, France, Spain, the Americas and Taiwan, and can be spread through the movement of infected plant material and through insects from the *Cicadellidae* and *Ceropidae* families. There are four known sub-species: *Xylella fastidiosa subsp*. multiplex, *Xylella fastidiosa subsp. fastidiosa, Xylella fastidiosa subsp. pauca* and *Xylella fastidiosa subsp*. *Sandyi.* The subspecies multiplex is thought to be able to infect the widest variety of trees and plants, including *Quercus robur* and *Platanus occidentalis*.

For further information on the pests and diseases listed above, as well as other pathogens that pose a threat to the UK's trees, please visit https://www.forestresearch.gov.uk/tools-and-resources/pest-and-disease-resources.

6.5 Appendix V. Notes on Methodology

Data Formatting

Life Expectancy (years)	Condition Rating	i-Tree Equivalent
80 +	Good Condition	87%
40 - 80	Good Condition	87%
10 - 20	Fair Condition	82%
20 - 40	Fair Condition	82%
< 5	Poor Condition	62%
05 - 10	Poor Condition	62%
None	Fair	82%

Table 11: Condition Ratings for use in Eco

Crown Condtion	LE Value	LE Percentage
87%	40 - 80	95%
82%	20 - 40	80%
62%	10 - 20	55%
0	0	0%

Table 12: CAVAT Assumptions

6.6 i-Tree Methodology

i-Tree Eco is designed to use standardised field data and local hourly air pollution and meteorological data to quantify forest structure and its numerous effects, including:

- Forest structure (e.g., species composition, tree health, leaf area, etc.)
- Amount of pollution removed hourly by trees, and its associated percent air quality improvement throughout a year. Pollution removal is calculated for ozone, sulphur dioxide, nitrogen dioxide, carbon monoxide and particulate matter (<2.5 microns).
- Total carbon stored and net carbon annually sequestered by trees
- Effects of trees on building energy use and consequent effects on carbon dioxide emissions from power plants
- Structural value of the forest, as well as the value for air pollution removal and carbon storage and sequestration
- Potential impact of infestations by pests, such as Asian longhorned beetle, emerald ash borer, gypsy moth, and Dutch elm disease

To calculate current carbon storage, biomass for each tree was calculated using equations from the literature and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations (Nowak 1994). To adjust for this difference, biomass results for open-grown urban trees were multiplied by 0.8. No adjustment was made for trees found in natural stand conditions. Tree dry-weight biomass was converted to stored carbon by multiplying by 0.5.

To estimate the gross amount of carbon sequestered annually, average diameter growth from the appropriate genera and diameter class and tree condition was added to the existing tree diameter (year x) to estimate tree diameter and carbon storage in year x+1.

The amount of oxygen produced is estimated from carbon sequestration based on atomic weights: net O_2 release (kg/yr) = net C sequestration (kg/yr) × 32/12. To estimate the net carbon sequestration rate, the amount of carbon sequestered as a result of tree growth is reduced by the amount lost resulting from tree mortality. Thus, net carbon sequestration and net annual oxygen production of trees account for decomposition (Nowak, Hoehn & Crane., 2007).

Recent updates (2011) to air quality modelling are based on improved leaf area index simulations, weather and pollution processing and interpolation, and updated pollutant monetary values.

Air pollution removal estimates are derived from calculated hourly tree canopy resistances for ozone, sulphur dioxide and nitrogen dioxide based on a hybrid of big-leaf and multi-layer canopy deposition models (Baldocchi 1987, 1988). As the removal of carbon monoxide and particulate matter by vegetation is not directly related to transpiration, removal rates (deposition velocities) for these pollutants were based on average measured values from the literature (Bidwell and Fraser, 1972; Lovett, 1994) that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere (Zinke 1967).

Annual avoided surface runoff is calculated based on rainfall interception by vegetation, specifically the difference between annual runoff with and without vegetation. Although tree leaves, branches and bark may intercept precipitation and thus mitigate surface runoff, only the precipitation intercepted by leaves is accounted for in this analysis. The value of avoided runoff is based on estimated or user-defined local values.

Replacement Costs were based on the valuation procedures of the Council of Tree and Landscape Appraisers, which use tree species, diameter, condition and location information (Hollis, 2007; Rogers *et al*., 2012).

For a full review of the model see UFORE (2010) and Nowak and Crane (2000).
For UK implementation see Rogers et al (2014).
Full citation details are located in the bibliography.

6.7 CAVAT

An amended CAVAT method was chosen to assess the trees in this study, in conjunction with the CAVAT steering group (as done with previous i-Tree Eco studies in the UK).
In calculating CAVAT the following data sets are required:

- The current Unit Value
- Diameter at Breast Height (DBH)
- The Community Tree Index (CTI) rating, reflecting local population density
- An assessment of accessibility
- An assessment of overall functionality, (that is the health and completeness of the crown of the tree)
- An assessment of Safe Life Expectancy

The current Unit Value is determined by the CAVAT steering group and is currently set at £16.26 (LTOA 2012).

DBH is taken directly from the field measurements.

The CTI rating is determined from the approved list (LTOA 2012) and is calculated on a City by City basis. The CTI for Cambridge is band 2.00, thereby increasing the basic CAVAT value.

Accessibility, i.e. the ability of the public to benefit from the amenity value of trees, was generally judged to be 100% for trees in Parks, street trees and other open areas, and was generally reduced for residential areas and transportation networks to 60% (increased to 100% if the tree was on the street), to 80% on institutional land uses and to 40% on Agricultural plots. For this study, park trees and street trees only were included, with 100% accessibility therefore assumed.

The Life Expectancy (LE) was partially provided and the remainder based upon the condition assessment. This therefore may not be fully accurate, especially for each individual tree.

For full details of the method refer to Doick, et al. (2018).

7.0 Bibliography

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