VALUING LONDON'S URBAN FOREST

Results of the London i-Tree Eco Project

i-Tree

“The urban forest is the ecosystem containing all of the trees, plants and associated animals in the urban environment, both in and around the city ”

Sands 2005.

First published in 2015
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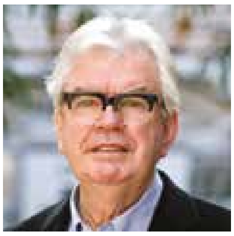
Foreword

Throughout my career as an architect, master planner, and government advisor I have been an advocate for urban trees. The importance of the natural environment, including trees, was one of the key elements in the recent Farrell review of PLACE (planning, Landscape, Architecture, Conservation and Engineering).



The importance of trees in the urban environment is unquestionable but is often minimised and lost amongst the myriad of other competing factors involved in urban space making, creation, management and maintenance.

I have been aware of i-Tree for a considerable time and have been interested in its potential to quantify the benefits of the urban forest in meaningful terms. It provides a methodology whereby trees can be valued and recognised as the asset they actually are.

In addition it provides the baseline information necessary for long term integrated and planned management of the urban forest.

I am aware of other UK i-Tree studies, but it gives me great pleasure and satisfaction to write the foreword to this report about London's Trees. The London i-Tree study represents the most extensive urban tree survey carried out in the world to date. The Greater London Authority, the Forestry Commission, Treeconomics, the i-Tree steering group and all of the many people involved in the production of this extensive and hugely significant report are to be congratulated.

I await, with expectant anticipation, its reception in the public domain and the positive outcomes for London's trees which I hope will result.

Sir Terry Farrell, CBE

Matthew Pencharz
Deputy Mayor for Environment & Energy
Most Londoners understand instinctively that trees are important and that is why the Mayor initiated his street tree programme and has required more trees to be planted by developers. Robust evidence of the economic worth of London's trees is essential to enable us to make the case for continued investment in our trees in the longer term. The report of the Green Infrastructure Task Force calls for better valuation of our green infrastructure assets, and this i-Tree survey is an excellent contribution to towards meeting that ambition. It provides a different, and hugely important, perspective on the value of London's urban forest.

Sir Harry Studholme
Forestry Commission Chairman
This is an excellent report, I welcome its publication and congratulate the very many people involved in its production. Valuing our environment is important. The Government Forestry Policy statement encourages the use of valuation systems. This has been backed up by the Natural Capital Committee's report. Valuation provides evidence of the immense benefits of trees and woodland and shows why taking care of our urban forest makes economic sense. One of the London Tree and Woodland Framework objectives was to raise awareness and understanding. This report does just that, making sure we can not ignore the wealth contained in London's trees.

Martin Kelly
Chair of Trees and Design Action Group
The London Plan (2015) directed boroughs to take the work of the Trees and Design Action Group into account in producing LDF policies and determining planning applications (para. 7.65).
It proposed that costs benefit analysis for the future value of trees, especially large growing trees, should also be recognised. TDAG welcomes the launch of the London i-Tree survey as it provides the tool by which these values can be assessed.

Unilever
Unilever is delighted to support the publication of this report as part of *For the Love of Trees – London*, a programme to highlight the value of London's urban forest and actively engage in the planting of 40,000 trees across London to enhance neighbourhoods and schools. Unilever is campaigning to raise awareness of the importance of trees and forests and aims to reconnect Londoners with their love of trees whilst shining a light on the issue of global deforestation through its brightFuture campaign. The findings of this i-Tree report provide vital evidence to raise the profile and demonstrate the value of London's trees.

With Thanks

The Authors

Kenton Rogers
Treeconomics

Keith Sacre
Barchams

Jessica Goodenough
Treeconomics

Kieron Doick
Forest Research

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Daniel Belucci
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David Hutchens
David Mercer
David Wheatley
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Diego Avesani
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John Eborall
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Kate Williams
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Matthew Hird
Matthew Payne
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Oliver Tong
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Paul Barton
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Pat Gardiner
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Patrica Knight
Peter Fischer
Pherenice Worsey-Buck
Polly Turton
Poppy Lakeman-Fraser
Rachel Carlill

Richard Edwards
Richard Ince
Robert Butcher
Robert Goode
Robert Shilston
Robin Middleton
Rosabel Richards
Rose Ades
Rosie Pope
Rupert Bentley-Walls
Russell Ball
Russell Miller
Saima Raza
Sally Harries
Samantha Davenport
Sarah Milliken
Sarah Riddlestone
Sarah Ward
Sean Courtman
Shaun Kiddell
Si Braybrooke,
Simon Ffoulkes
Sonu Agarwal
Sophie Da Costa
Stephen Downing
Stephen Middleton
Stephen Whittle
Susanna Ferrar
Susanne Raum
Suzanne Flanagan Corke
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Executive Summary

The millions of trees and shrubs in London's parks, gardens, woodlands and open spaces are collectively described as London's 'urban forest'.

This urban forest is part of London's green infrastructure. It provides a range of ecosystem services that delivers multiple environmental benefits to Londoners. The scale and effectiveness of these benefits, such as air quality improvement, carbon sequestration or temperature reduction, are directly influenced by the way we manage the resource and decisions and actions that affect its structure and composition over time.

We know that maintaining and improving London's urban forest has considerable public support, but also that much of the urban forest has grown and matured over many years in conditions very different from the cityscape of today. Consequently, we need to have a good understanding of the structure and value of London's urban forest to ensure that we are implementing appropriate management, maintenance and planting regimes that will result in maintaining and increasing the canopy cover over time.

A first and necessary step is to better understand the current structure, composition and distribution of London's urban forest, in order to obtain a baseline from which to set goals and to monitor progress. Furthermore, by measuring the structure of the urban forest (the physical attributes such tree density, tree health, leaf area and biomass), the benefits of the urban forest can also be determined, and the value of these benefits calculated and expressed in monetary terms.

With the value of the resource expressed in ways that provide a new perspective on the benefits of London's urban forest, we can make more informed decisions about its management and maintenance, and encourage the investment needed to deliver improvements to London's environment and the health of Londoners.

To achieve this better understanding of London's urban forest the RE:LEAF partnership has undertaken an urban forest assessment using the i-Tree Eco Tool.

This report presents the outcome of this assessment. It provides a quantitative baseline of the air pollution, carbon storage and sequestration benefits of trees as well as the amenity and stormwater benefits they provide. This is supported with detailed information on the structure and composition of London's urban forest.

London's Urban Forest - Key Statistics				Total
Number of Trees	Inner London	1,587,000		8,421,000
	Outer London	6,834,000		
Tree Cover	Inner London	13%		14%
	Outer London	14%		
Canopy Cover	Inner London	18%		21%
	Outer London	21%		
Most Common Species	Inner London	Birch, Lime, Apple		
	Outer London	Sycamore, Oak, Hawthorn		
Pollution Removal (per annum)	Inner London	561 tonnes	£58 million	£126.1 Million
	Outer London	1680 tonnes	£68.1 million	
Stormwater Alleviation (per annum)	Inner London	705,000m³	**£568,935**	£2.8 Million
	Outer London	2,709,000m³	**£2.2 million**	
Carbon Storage (whole value)	Inner London	499,000 tonnes	£30.9 million	£146.9 Million
	Outer London	1,868,000 tonnes	£116 million	
Carbon Sequestration (per annum)	Inner London	15,900 tonnes	£987,000	£4.79 Million
	Outer London	61,300 tonnes	£3.8 million	
Building Energy Savings (per annum)	Inner London	£223,000		£260,600.00
	Outer London	£37,600		
Building Avoided Carbon Emissions (per annum)	Inner London	£23,600		£54,600
	Outer London	£31,000		
Replacement Cost (whole value)	Inner London	£1.35 Billion		£6.12 Billion
	Outer London	£4.77 Billion		
Amenity Value (CAVAT) (whole value)	Inner London	£17.6 Billion		£43.3 Billion
	Outer London	£25.7 Billion		
TOTAL ANNUAL BENEFITS	Inner London	£59.54 Million		£132.7 Million
	Outer London	£73.16 Million		

Notes

Number of trees: Total number of estimated trees extrapolated from the sample plots.

Tree cover: Total tree canopy cover taken from direct measurements from within plots, this value excludes shrubs (shrub cover was estimated at 4.9% in Inner London, 7.2% in Outer London and 6.7% for Greater London).

Canopy cover: is the total of tree and shrub cover. Please note that due to the survey methodology (using 721 plots) we acknowledge that the reported canopy cover figures are lower than other reported studies using a random point method (typically 10,000 plots) and therefore this report provides a statistically robust while still conservative estimate of the natural capital of London and the ecosystem services that it provides.

Most common species is based on field observations.

Pollution removal value is calculated based on the UK social damage costs (UKSDC) and the US externality prices (USEC) where UK figures are not available;
For Inner London these were; £927 per metric ton CO (carbon monoxide - USEC), £6,528 per metric ton O_3 (ozone - USEC), £98,907 per metric ton NO_2 (nitrogen dioxide - UKSDC), £1,633 per metric ton SO_2 (sulphur dioxide - USEC), £273,193 per metric ton PM_{10} (Particulate matter less than 10 microns and greater than 2.5 microns - UKSDC), £7,482 per metric ton $PM_{2.5}$ (particulate matter less than 2.5 microns - USEC).

For Outer London these were; £927 per metric ton CO (carbon monoxide - USEC), £6,528 per metric ton O_3 (ozone - USEC), £64,605 per metric ton NO_2 (nitrogen dioxide - UKSDC), £1,633 per metric ton SO_2 (sulphur dioxide - USEC), £178,447 per metric ton PM_{10} (Particulate matter less than 10 microns and greater than 2.5 microns - UKSDC), £7482 per metric ton $PM_{2.5}$ (particulate matter less than 2.5 microns - USEC).

Stormwater Alleviation is based on the amount of water held in the tree canopy and re-evaporated after the rainfall event (avoided runoff). The value is based on the Thames Water volumetric charge of £0.807p per cubic metre.

Carbon Storage: the amount of carbon bound up in the above-ground and below-ground parts of woody vegetation.

Carbon sequestration: the removal of carbon dioxide from the air by plants.

Carbon storage and carbon sequestration values are calculated based on 2015 DECC figures of £62 per metric ton.

Building Energy saving value is calculated based on the prices of £149.20p per KWH and £14.06 per MBTU.

Replacement Cost: is the value of the trees based on the physical resource itself (e.g., the cost of having to replace a tree with a similar tree).

Amenity Value: is calculated using the Capital Asset Valuation for Amenity Trees (CAVAT) method.

Further details are found within the relevant chapters of the report and a summary of the calculations is included within appendix IV.

Contents

Introduction

Urban trees provide a range of beneficial services that are of particular importance in the urban environment. Despite widespread public appreciation of the amenity value of trees, the full range of benefits provided by the urban forest are often unnoticed, unappreciated and undervalued. Recognising and evaluating these benefits can help us to make the right decisions about how best to manage our urban trees.

Natural capital refers to the elements of the natural environment, such as the trees and shrubs of an urban forest, that provide valuable goods and services to people, including clean air, food and recreation. As the benefits provided by natural capital are often not marketable they are generally undervalued. Inventories on the natural capital are limited, where they exist at all. This may lead to wrong decisions being made about the management and maintenance of natural capital.

Some of these benefits or "ecosystem services" are visualised in fig 1 (page 16).

Some of the ecosystem services provided by urban trees are quantifiable using models such as i-Tree Eco. i-Tree Eco is currently the most complete method available to value a whole suite of urban forest ecosystem services (Natural England, 2013), including pollutant interception and carbon uptake. i-Tree Eco has been used successfully in over 100 countries, including several cities in the UK. It is also capable of providing detailed results on the structure and functions of the trees that make up the urban forest.

> # By FAO definition (a contiguous area with over 10% tree canopy cover) London can already be classified as a forest.
>
> **The Food and Agriculture Organisation of the United Nations**

The Millennium Ecosystem Assessment (MEA) (2005) and the UK National Ecosystem Assessment (UKNEA) (2011) provide frameworks to examine the possible goods and services that ecosystems can deliver, according to four categories: provisioning, regulating, supporting and cultural services. The ecosystem services valued by i-Tree Eco plus the other ecosystem services considered within this report are presented in Table 1 (below).

Given the importance of the urban tree resource, knowledge of the contribution that trees make to our natural capital needs to be available for strategic planning and management purposes. This requires that key information be gathered so that the urban forest can be protected and enhanced, and its crucial functionality maintained.

Table 1 shows that many of the ecosystem services provided by urban trees are not quantified or valued by i-Tree Eco. The value of London's urban forest presented in this report should therefore be recognised as a conservative estimate of the total value of the full range of benefits that the urban forest provides to Londoner's.

It is also important to recognise that i-Tree Eco provides a 'snapshot in time' of the size, composition and health of an urban forest. Only through comparison to repeat i-Tree Eco studies, or studies using a comparable data collection method, can an analysis of change be conducted.

Provisioning	Regulating	Supporting	Cultural
Food	Climate mitigation	Soil formation	Social cohesion
Wood	Carbon storage and sequestration	Biodiversity / habitats for species	Visual amenity
	Pollution mitigation (air and water)	Oxygen production	Recreation, mental and physical health
	Flood and water protection		Landscape and sense of place
	Soil protection		Education

Table 1. List of ecosystem services provided by the urban forest arranged according to the MEA categories of Provisioning, Regulating, Supporting and Cultural services. Ecosystem services considered within this report are underlined, those that are also valued are in bold.

The Benefits of Trees

Fig 1.

Energy Saving

Trees located alongside buildings can act as a secondary insulating layer, regulating temperatures around buildings. If well placed, trees can help keep buildings cool in the summer and warmer in the winter.

Property Value

Tree-lined streets have been proven to increase house prices by as much as 15%. Most people chose to live in and/or around trees where possible.

Improving Air Quality

Trees filter fine particles from the air reducing pollution and improving health.

Storm Water Attenuation

Trees help to reduce localised flooding by intercepting rainfall and maintaining soil permeability.

Shade and Cooling

Trees cool the air by providing shade and through evapotranspiration from their leaves. Larger canopy species are particularly effective.

Aesthetic
Trees bring a sense of place and maturity to new developments, whilst larger species help to create a more human scale to old and existing townscapes.

Storing Carbon
As trees grow they accumulate carbon in their woody tissues, reducing the amount of this greenhouse gas in the atmosphere.

Urban Forest Food
Trees provide fruit and nuts for wildlife and humans. They also provide an important source of nectar for bees and other insects.

Biodiversity and Habitat
An increase in tree diversity will benefit a host of insects, birds and mammals in our towns and cities.

Landscape Screening
Not everything in cities is aesthetically pleasing and in some instances, trees and other vegetation can be of assistance in screening undesirable views.

Assists Recovery
Helps improve recovery times from illness, reduces stress plus improves mental health and well being.

Focal Point
Improves social cohesion. Reduces crime.

Methodology

i-Tree Eco is designed to use standardised field data from randomly located plots across the whole study area. This field data is combined with local hourly pollution and meteorological data to provide a snap shot picture of the ecosystem services provided by trees and shrubs within the study area.

For the London i-Tree Eco assessment, a total of seven hundred and twenty four plots were randomly selected from both Inner and Outer London. 200 plots were located in Inner London and 524 plots were located in Outer London (Fig 2). This provided a statistically relevant sample size.

The area of Greater London is 159,470[1] ha which resulted in a sample plot every 220 ha. 31,012 ha of the total study area was situated in Inner London with a plot every 155 ha and 128,458 ha located in Outer London with a plot every 245 ha.

i-Tree Eco uses a standardised field collection method outlined in the i-Tree Eco Manual (v 5.0 for this study) (i-Tree 2013). This method was applied to each plot. Each plot covered 0.04 ha.

Field data was collected by volunteer teams led by a professional arborist or forester, plus professional survey teams from Treeconomics, the London Tree Officers Association (LTOA), Forestry Commission and Forest Research.

A total of 476 plots were assessed using volunteers with the remainder of plots surveyed by the professional teams. Training of volunteers was carried out by Treeconomics, Forestry Commission and Greenspace Information for Greater London (GiGL) during the late spring and summer of 2014. Over 200 volunteers were trained for the study.

Volunteers were enlisted as a result of a collaborative initiative by the RE:LEAF partnership which co-ordinated training, logistics, access arrangements and field work during the study period. Recruitment of volunteers was led by Trees for Cities and the Tree Council to harness local support and ownership of the i-Tree Eco project.

1 Source: GiGL

Jim Smith, Forestry Commission England - conducts training with the volunteers

Volunteers used iGiGL (www.gigl.org.uk/online) to locate and review maps of their survey plots. The information gathered from each plot was recorded on paper data sheets and then uploaded into an online form hosted by GiGL.

The information recorded from each plot was as follows:

- The type of land use encountered. For example park, residential, etc.
- The percentage distribution of ground cover present in the plot. For example grass, tarmac, etc.
- The percentage of the plot available for future tree planting.

The following specific information about trees with a stem diameter above 7cm and above at 1.3m high was recorded. Trees below this size were not considered as part of the survey following standard forestry practice.

- The number of trees and species of trees present.
- The size of the trees, including height, canopy spread and diameter of trunk
- The health of the trees including the fullness of the canopy and percentage of canopy missing.
- The amount of light exposure the canopy receives.

Information about shrubs less than 7cm in trunk girth was also gathered with the size and dimensions of shrubs recorded.

From this data a three dimensional numeric model of the total biomass, its distribution and condition is constructed within the i-Tree model enabling the calculation of the total ecosystem services delivered to be calculated.

Data collected in the field was submitted to the US Forest Service for use in the i-Tree Eco model and a number of outputs calculated (Table 2 below). i-Tree Eco calculates the species and age class structure, biomass and leaf area index (LAI) of the urban forest. This data is then combined with local climate and air pollution data to produce estimates of a number of ecosystem services (Table 2) and to assess their current and future value.

Weather data was for the year 2013, recorded at Hampstead weather station in the North of Inner London, data was collected from NOAA (2014). $PM_{10's}$ were recorded at Hillingdon Station in the West of greater London for the year 2013. NO_2 (2013), CO (2013), SO_2 (2013), $PM_{2.5's}$ (2013), O_3 (ozone) (2011) and SO_2 (2011) were recorded at Kensington/Chelsea station in the west of Inner London. All pollution data was obtained from DEFRA (2014).

From this an estimate of the current and future ecosystem services delivered by London's Urban Forest can be determined with separate calculations for Inner and Outer London.

Urban Forest Structure and Composition	Land Use and Ground cover, Species and size class distribution, Species Dominance, Leaf Area and Canopy Cover, Tree Diversity, Biodiversity and Pollinators
Ecosystem Services	Air pollution removal by urban trees for CO, NO_2, SO_2, O_3 , PM10 and 2.5. % of total air pollution removed by trees. Current Carbon storage. Carbon sequestered. Storm Water Reduction. Building Energy Effects
Structural Values	Replacement Cost in £. Amenity Value in £ using Capital Assest Valuation for Amenity Trees (CAVAT)
Potential insect and disease impacts for any potential or existing pathogen including….	Acute oak decline, asian longhorn beetle, chalara dieback of ash, emerald ash borer, gypsy moth and plane wilt

Table 2. Outputs of the study.

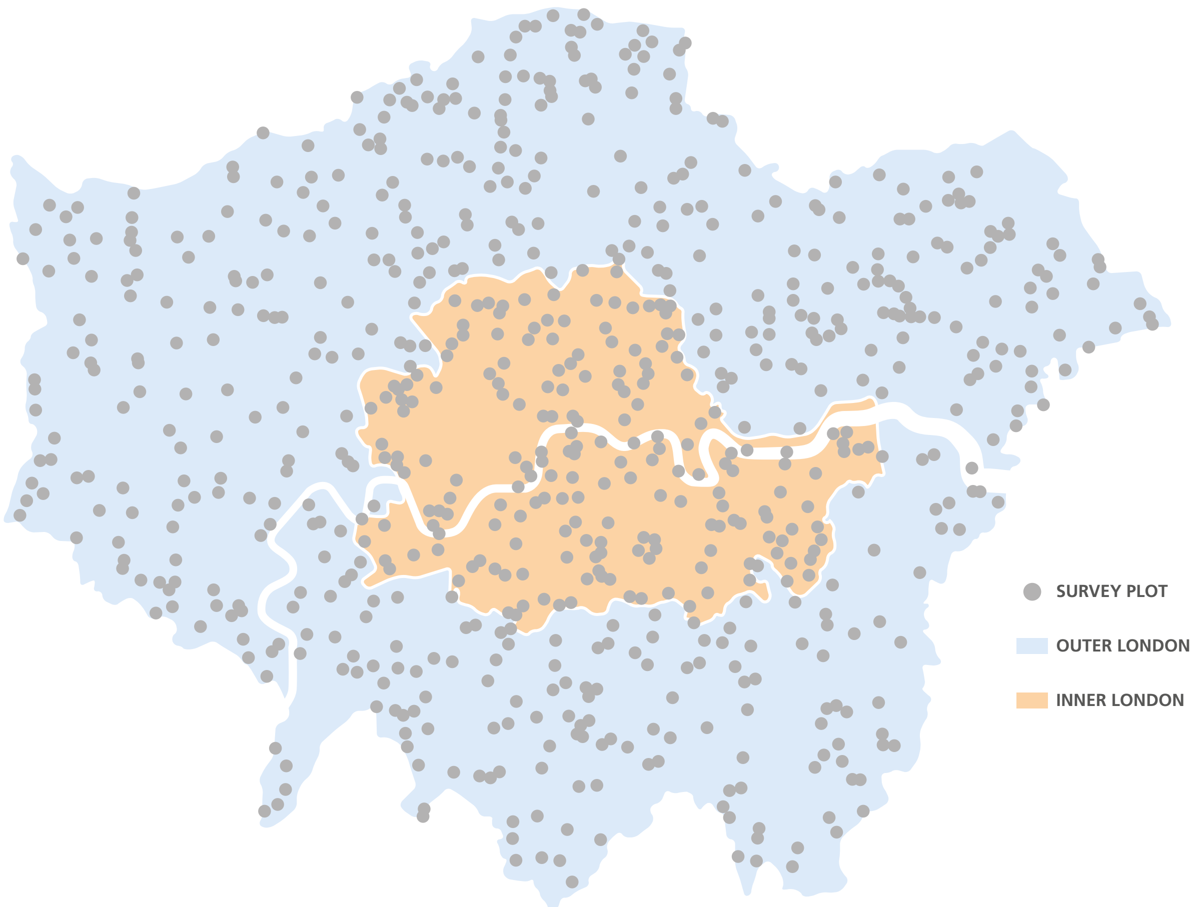

Fig 2. Sample area and plot distribution for the study

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Volunteers Perspective

"When I heard about the London-wide i-Tree survey, I jumped at the chance to volunteer. As a Londoner, I am well aware of the importance and value of London's trees and wanted to be a part of the project that would quantify that value."

Laura Gardner
i-Tree volunteer team leader

"The training was great; both for getting to meet other volunteers and finding out why other people wanted to be a part of the survey. I loved learning from the wealth of knowledge that Jim Smith and Keith Sacre share between them.

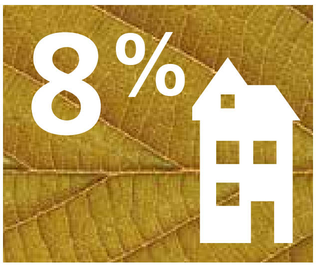
While my team were all available in the same area of London, not all were available at the same time, which added to the challenge of making sure everyone had a chance to get out and survey and meant that each team member was only able to survey three or four sites.

Once we were out surveying though, the experience was great - even with two sites in the middle of the Thames! We covered a wide area with really different types of site: the South Bank (in the river), terraced housing, an adventure playground, waste land, a housing estate and a courier company's forecourt. We did find some trees on all plots that were on dry land, and found local residents to be both helpful and really interested in the survey: why we were doing it and what we were finding out.

Typing up the findings was a good opportunity to warm up with a hot chocolate and get to know the team a bit more. I can't wait to see the results and find out what that means for London's trees".

Results/Analysis

The Structural Resource - Land Use and Ground cover



The percentage of land classified as multi-residential (flats, apartments etc) varies significantly between Inner London (12%) and Outer London (3%)

Based on an assessment of Land use from each of the randomly located plots, the i-Tree Eco model estimates that land use in London is as follows.

An estimated 32% of the land in Greater London is classified as residential. This percentage varies marginally between Inner London (33.6%) and Outer London (30.5%).

The percentage of land classified as parks and gardens is higher in Inner London (16%) than Outer London (10%) but the percentage of land classified as agricultural, which includes woodlands, is significantly higher in Outer London (16%) than Inner London where only 0.5% of land is classified this way.

On average 14.5% of land is classified as being used for transportation in Greater London but again the percentage for Inner London (17.1%) and Outer London (11.9%) varies.

The percentage of land classified as commercial in Greater London (7.1%) varies slightly between Inner London (6.4%) and Outer London (7.8%).

Other land uses are represented by smaller percentages of the whole. Water and wetlands account for 2.6% of land use across Greater London but the percentage of land classified in this way varies with Inner London (3.5%) having double the amount of land in this category than Outer London (1.7%).

Golf courses represent 2.6% of land use in Greater London but the percentage in this land use category for Outer London (3.9%) is more than double that of Inner London (1.2%).

For the full breakdown of Land Use Cover Classes see fig 3 below.

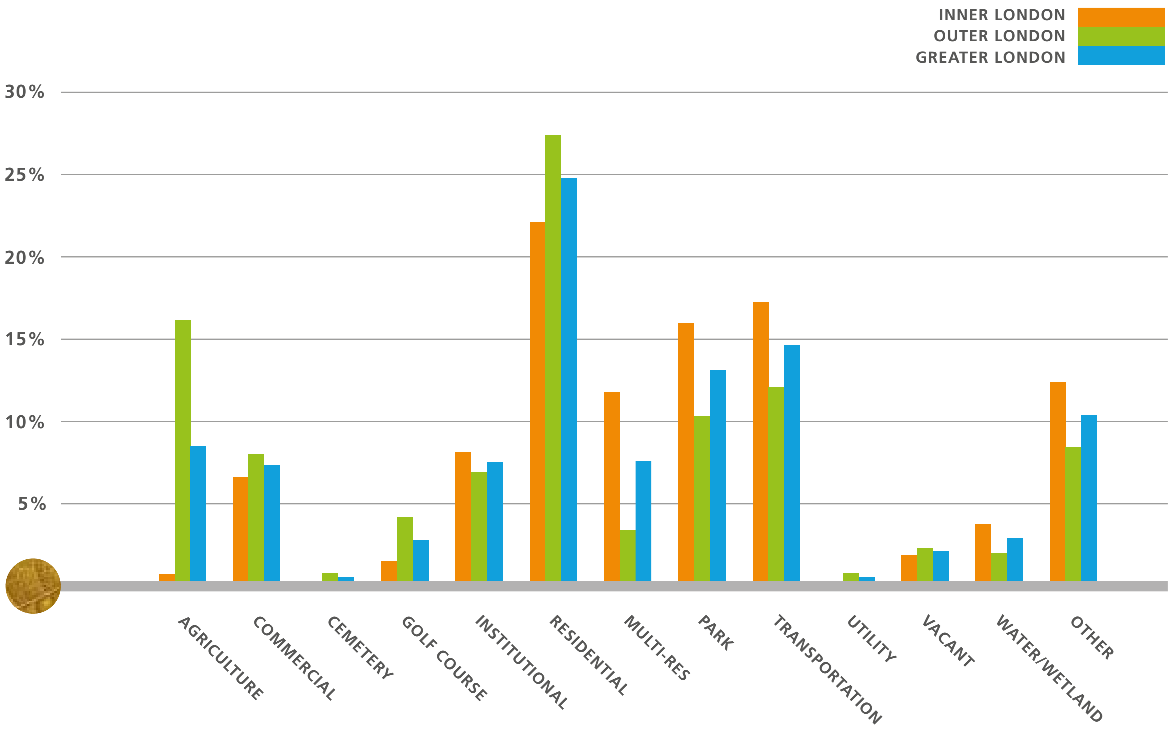


Fig 3. Land use in London.

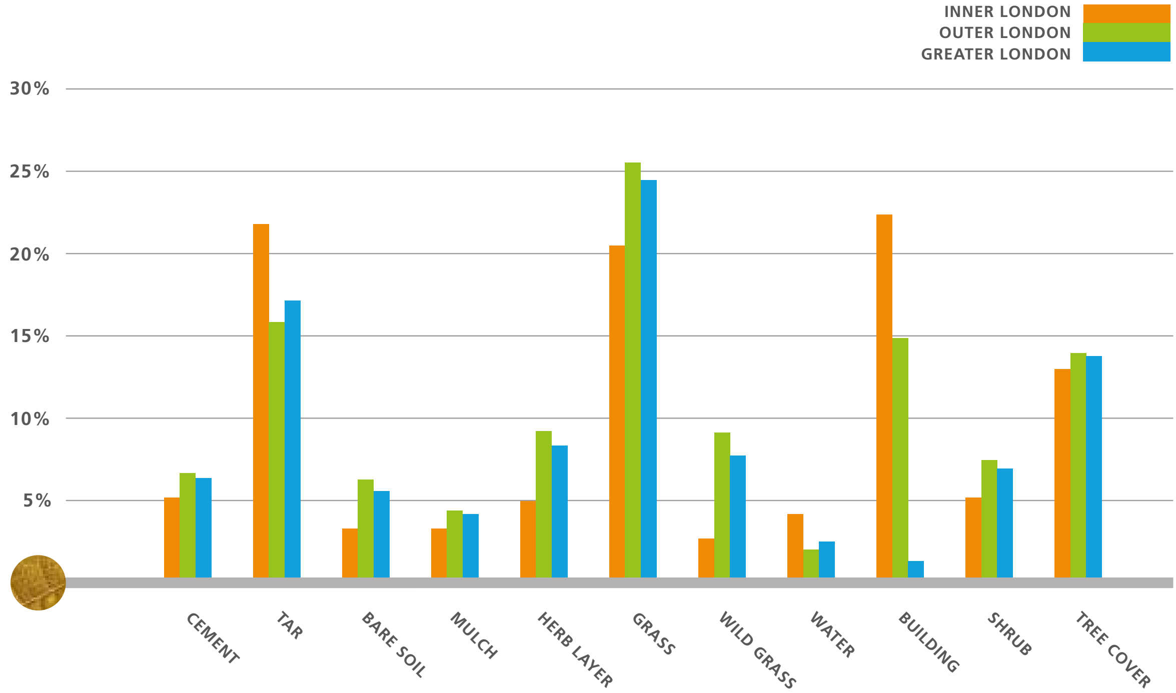


Fig 4. Ground Cover in London.

Ground Cover

Ground cover refers to the various surfaces found within each sample plot area.

For example, the ground cover for a plot located within an industrial estate, will have a 'commercial' land use, but it will also have various ground cover types present within it, such as grass, tarmac and bare soil.

Additionally, there may also be a percentage of the ground covered by an existing tree canopy. The percentage of this tree cover was also recorded and is in addition to ground cover (because a tree canopy will overhang the existing ground cover, be that grass or tarmac.

Furthermore, a percentage of the ground within each plot which was theoretically available for new tree planting was also recorded as plantable space. However this figure is indicative only as it makes no allowance for any underground services or constraints.

The i-Tree Eco assessment identified the following ground cover percentages London.

In Greater London 31.9% of ground cover is classified as grass. Of this 24.4% is classified as maintained grass and 7.5% classified as wild grass. Outer London has 25.5% of its ground cover classified as maintained grass with Inner London (20.4%) having a smaller percentage. The percentage of land use classified as wild grass varies significantly between Inner London (2.4%) and Outer London (8.9%).

A total of 39.5% of ground cover in Greater London is impermeable. This is classified as either, building, tarmac or cement. Of this ground cover classification 23.1% is either tarmac or cement and 16.4% buildings. There is some variance between Inner London (26.3%) and Outer London (22.3%) in ground cover classified as either cement or tarmac. There is also variance between Inner London (22.3%) and Outer London (14.7%) of ground cover classified as building.

A percentage of ground cover in Central London (5.3%) is classified as bare soil but the area in Outer London (6%) is twice as much as that for Inner London (3%).

For the full breakdown of Land Use Cover Classes See fig 4 above.

The Structural Resource - Trees

London has an estimated tree population of 8.4 million trees. The trees that make up London's urban forest are situated on both public and private property. It is estimated that 57% of these trees are in private ownership and 43% in public ownership.

1.6 million of London's trees are situated in Inner London and a further 6.8 million within Outer London. Tree density is 53 trees per ha, this is lower than densities recorded for other i-Tree surveys (see table 3 below) and the UK average for towns and cities of 58 trees per ha[2].

Trees with a diameter at breast height less than 15cm constitute 35% percent of the population (42% for Inner London and 34% in Outer London).

The three most common species across London are sycamore (*Acer Pseudoplatanus*) at 7.8% of the population, English oak (*Quercus robur*) at 7.3%, and silver birch (*Betula pendula*) at 6.2%.

In Inner London Birch (*Betula spp*), Lime (*Tilia cordata*) and Apple (*Malus spp*) are the three most commonly recorded trees with 11.7%, 6.2% and 5.9% of the population respectively[3].

In Outer London the three most common species recorded were sycamore (*Acer Pseudoplatanus*) at 8.5%, English oak (*Quercus robur*) 8.3% and hawthorn (*Crataegus monogyna*) with 6.8% of the population.

	Greater London	Glasgow	Barcelona	Toronto	Chicago City Metro Region	Chicago City Area
Study area (ha)	159,470	17,643	10,121	66,140	2,812,000	147,510
Plots	721	200	579	407	2076	745
Plots every ___ ha	221	88	17	163	1355	198
Tree Cover (%)	14	15	25	24	16	17.2
Total Number of Trees	8,421,000	2,000,000	1,419,000	10,200,000	157,142,000	3,585,000
Trees (per ha)	53	112	140	154	56	24.3

Table 3. Comparison of Tree Resource from other i-Tree Eco studies .

For a functioning urban forest there needs to be trees of all shapes and sizes and in the right proportions to ensure that benefits can continue to be delivered for future Londoners.

2 Britt and Johnston 2008
3 When leaf area is considered rather than just population, however, the dominance of London Plane becomes apparent.

For species composition see fig 5 right. Full details of tree composition for each species are given in Appendix III. Across London, the ten most common species account for 49% of the total population.

In total, 126 tree species were recorded in the survey. This is currently the highest recorded species diversity of any urban forest analysed with i-Tree Eco in the UK. As discussed later, increased tree diversity has the potential to minimise the impact or destruction of species by specific pathogens and diseases and from climate change.

It is worth noting that as a sample survey the total number of species recorded is not the absolute total number species that would be found across London. For example there are around 2000[4] species and varieties of tree within the grounds of Kew Gardens alone. However, the survey does provide a good estimate of the most frequently encountered species based on the sample size.

Size class distribution is another important factor in managing a sustainable tree population, as this will ensure that there are enough young trees to replace those older specimens that are eventually lost through old age or disease (fig 7 page 28).

In this survey trees were sized by their stem diameter at breast height (dbh) at 1.3m. Fig 6 (right) illustrates the size range of trees within London from tree diameters at breast height (dbh).

The majority of trees within London are within the lowest size categories, 70% of the trees recorded have a dbh of less that 30cm, whilst around 35% of the trees have diameters less than 15cm.

Across London approximately 30% of the tree population is larger than 30cm dbh. This compares favourably with cities and towns in other regions of England where the Trees in Towns 2 survey found that on average only 10-20% of trees have a dbh that is greater than 30cm (Britt and Johnston, 2008).

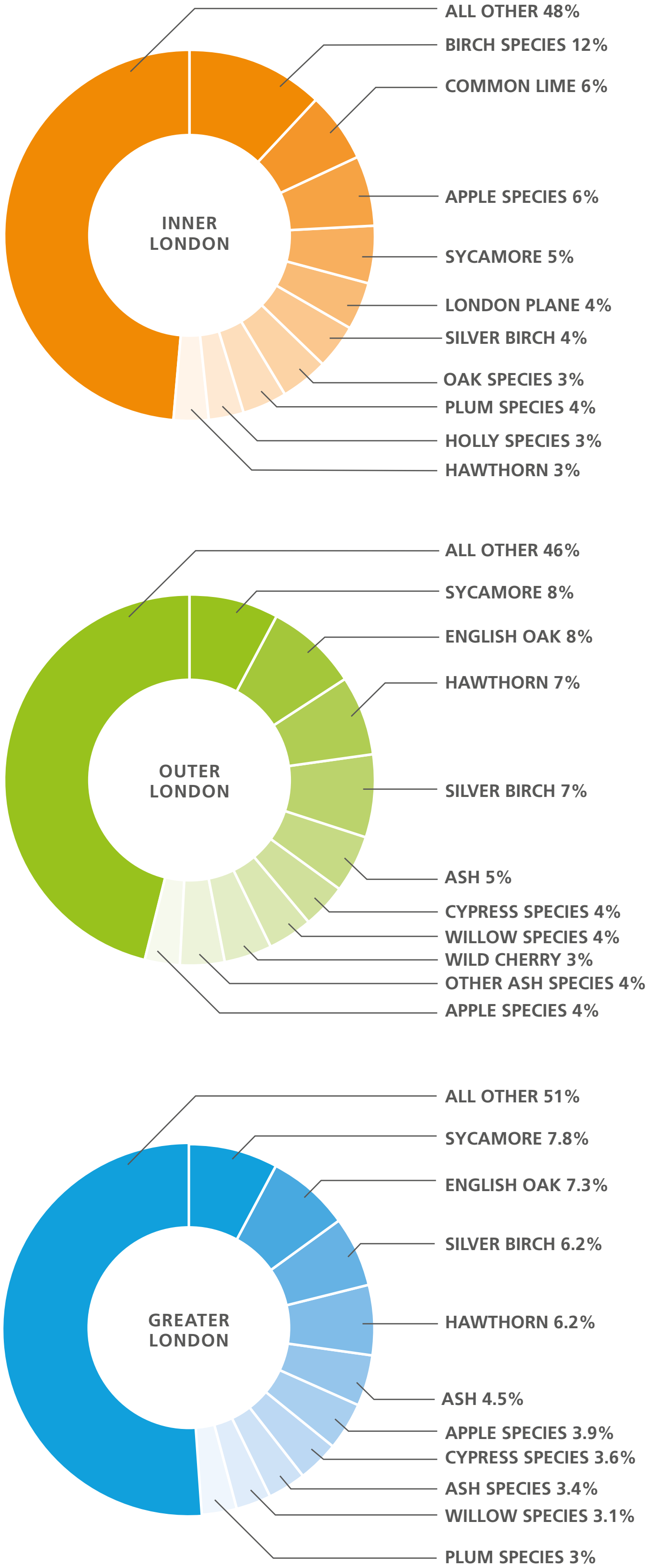


Fig 5. Species Composition for the 10 most common species in Inner, Outer and Greater London.

4 Source: http://www.kew.org/visit-kew-gardens/explore/attractions/arboretum

This might show an insufficient succession or reliance on over mature trees and a lack of tree planting over certain periods in the past 100 years.

The number of trees in each dbh class declines successively and trees with dbh's higher than 60 cm make up less than 5% of the tree population.

The size distribution of trees is an important consideration for a resilient population. Large, mature trees offer unique ecological roles not offered by smaller or younger trees[5]

To maintain a level of mature trees, young trees are also needed to restock trees as they age and need to be planted in a surplus to include planning for mortality.

Work by Richards (1983) proposes an 'ideal' tree size distribution which has been adopted by cities such as Toronto to inform decisions about tree population management.

Fig 7 (page 28) illustrates London's tree size distribution against this ideal and a selection of other international cities who have carried out i-Tree Eco assessments. This 'ideal' is intended as a guideline only. Forests are unique and there is no 'one size fits all' target distribution. However, the proportion of trees with diameters between 40 and 60cm is low, suggesting a shortage of large sized trees in the near future. London would therefore benefit from a greater proportion of larger trees.

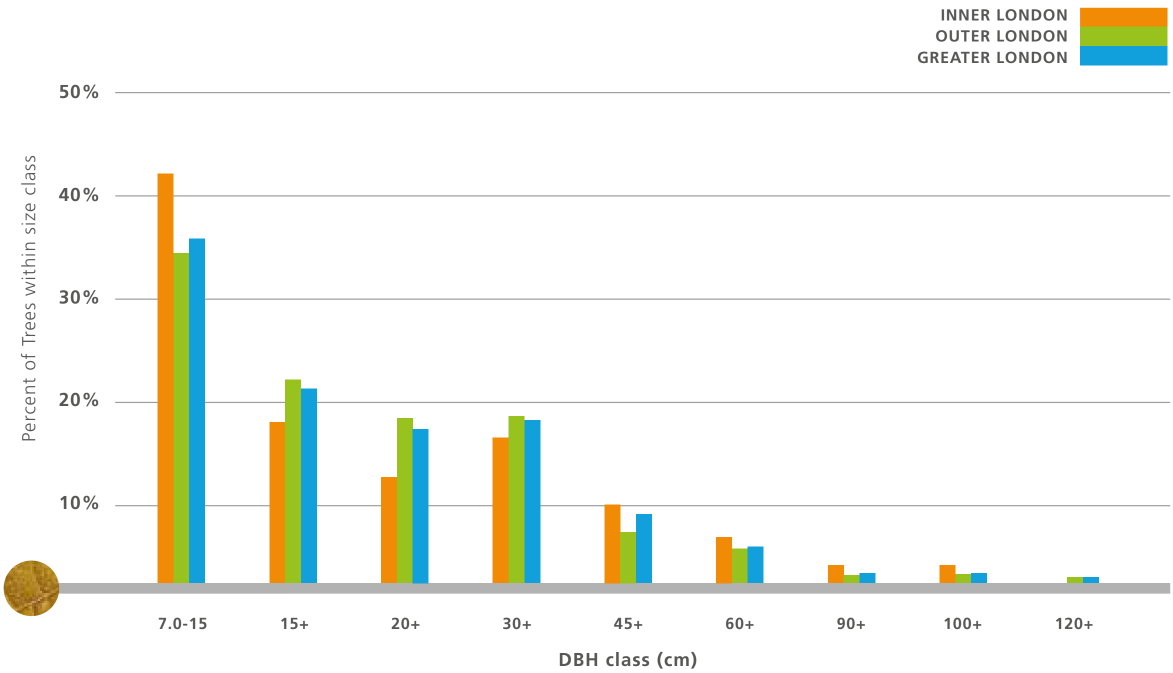


Fig 6. Size class distribution.

5 Lindenmayer, Laurance and Franklin (2012)

Small stature trees (trees that will never attain a maximum height of 10m) make up only a small percentage (less than 10%) of London's tree population. These trees will never attain a large stature, which must be borne in mind when planning for structural diversity. However it must be remembered that these smaller stature trees also contribute to the diversity and resilience of London's tree population.

At a very basic level a tree population ideally needs:

- Enough large and mature trees, to deliver the widest possible range of environmental benefits in urban areas.
- Enough trees in a number of younger age classes to replace these mature trees as they eventually die.

As well as planning for this scenario, urban tree managers must also allow for a proportion of mortality within the younger age classes in order to produce planting programs that will deliver maximum benefits over time.

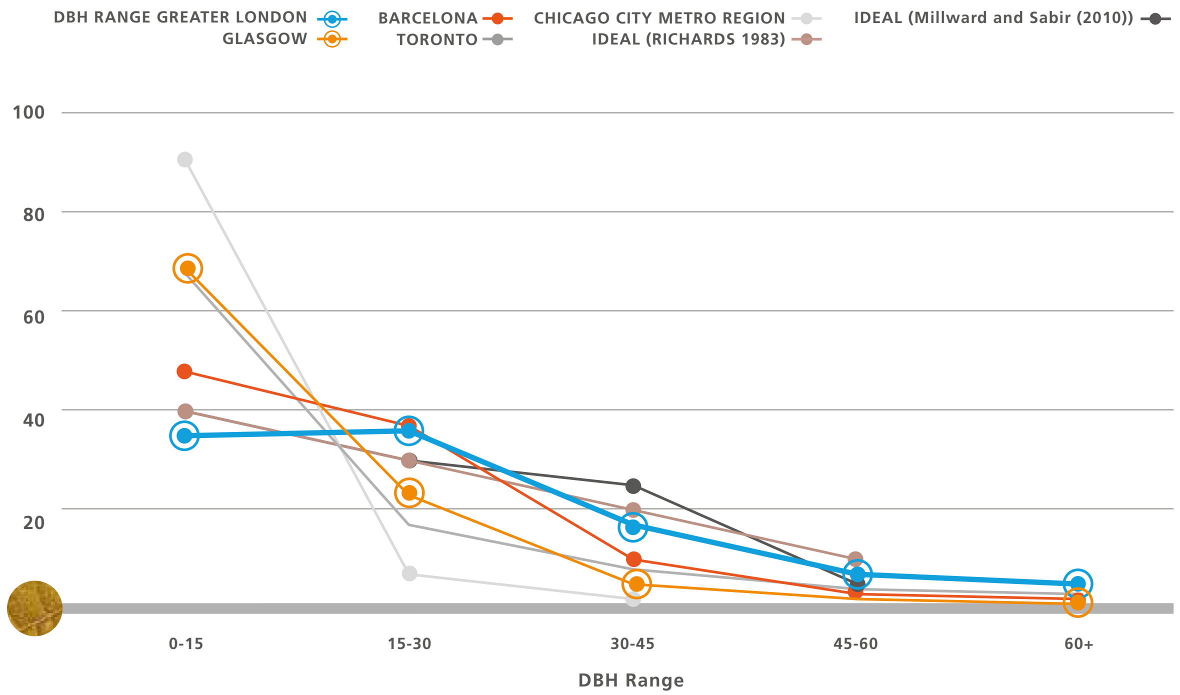


Fig 7. DBH ranges of trees encountered in London together with recommended frequencies for trees in each DBH class as outlined by Richards (1983).

A note on Tree Canopy **Assessment Methods**

Measuring the overall tree canopy (also referred to as urban tree cover, tree canopy cover, canopy cover or urban forest cover) is one of many possible indicators for assessing the extent of the urban forest.

For this study, visual estimates of tree cover were recorded for each plot, in addition to the shrub mass, which was also measured.

There are different methods for estimating tree canopy cover and it is important to note that these different approaches for estimating tree canopy cover will produce different results. This depends on the methodology, the definition of what constitutes 'cover' (trees, trees and shrubs, trees greenspace and shrubs, etc) and the resolution of the data (leaf on vs leaf off, aerial photos vs satellite imagery vs ocular estimates, etc).

Therefore, each study must be interpreted in context with consideration for the expected statistical accuracy. In comparison, in the Toronto urban forest study 3 different methods of assessing canopy cover were applied in 7 separate exercises. The difference in the lowest (17.5%) to the highest (28%) estimate was just over 10%. In this study, the standard error for tree canopy cover estimates where +/-1.35% for Inner London +/-1.04% for Outer London and +/- 0.86% for Greater London.

With this in mind we acknowledge that i-Tree Eco plot data can underestimate canopy cover compared to aerial methods such as i-Tree Canopy where a much greater number of sample points can be assessed. Furthermore, in this study in particular, study design led to a small bias where the protocol for inaccessible plots inadvertently led to a greater number of less 'treed' plots being surveyed.

However, this report still provides a robust valuation of the ecosystem services provided by the surveyed natural capital.

From previous aerial tree canopy surveys for London it is generally recognised that London tree cover is around 20%. An example of different canopy methods applied to London is given in table 4 below. Considering that the tree canopy could be nearer to 20% we consider that the ecosystem services valuations within this report could be almost doubled.

Study	Method	Year	Canopy Definition	Result
Trees in Towns 2	Field measurements	2005	Trees only	8.2%
i-Tree Eco Survey	Field measurements	2014	Trees only	13.6%
LTOA survey	5467 point sample	2012	Trees only	21.9%
GLA survey	3000 point sample	2013	Trees only	19.5%
Treeconomics survey	1000 point sample	2012	Trees and shrubs	27.4%

Table 4.

The Structural Resource - Leaf Area and Species Dominance

Although tree population numbers are a useful metric, when combined with measurements on leaf area a greater understanding of the importance that different species play in the delivery of benefits within the urban forest is obtained. This is because the main benefits derived from trees are directly linked to the amount of healthy leaf surface area that they have.

To demonstrate the proliferation of a species, the gross leaf surface area of that species, combined with its abundance in the overall population, indicates its relative contribution of benefits. This is termed the dominance value.

Taking into account the leaf area and relative abundance of the species i-Tree Eco is able to calculate the dominance value (DV) for each species ranking the trees in respect of their importance for the delivery of benefits or ecosystem services.

So whilst a species such as Apple (*malus spp*) may be the third most numerous tree in Inner London (with 6% of the population and 1.3% of the leaf area), it is actually the London Plane (4% of the population with 8.9% of the leaf area) that provides the most leaf area and therefore, the most associated benefits.

Across Greater London the most important species in the urban forest are sycamore (*Acer psuedoplatanus*), oak (*Quercus robur*) and silver birch (*Betula pendula*). In Inner London birch (*Betula spp*), London plane (*Platanus hispanica*) and lime (*Tilia cordata*) are the most important tree species.

Apple, which is the 3rd most populous tree, is ranked 8th for species importance. Whilst in outer London sycamore (*Acer pseudoplatanus*), oak (*Quercus robur*) and ash (*fraxinus excelsior*) are the most dominant and important trees in terms of the canopy cover they provide. Fig 8 (right) illustrates the 10 most important tree species across Greater London and within Inner and Outer London[6].

6 A full list of trees together with leaf areas and percentage of the overall population is given in Appendix II.

Leaf area and tree canopy cover is the driving force behind tree benefits

Fig 8. Ten most important/dominant tree species in Inner London (Top), Outer London (middle) and Greater London (bottom) These are the most dominant trees and as a consequence currently the most important in terms of Leaf area providing maximum benefits.

Tree species such as apple (*Malus spp*) and hawthorn (*Crateagus*) have a much smaller percent of leaf area compared to their percent of population as they are either smaller in stature (hawthorn) or in the case of cypress often kept smaller (as hedges) through pruning.

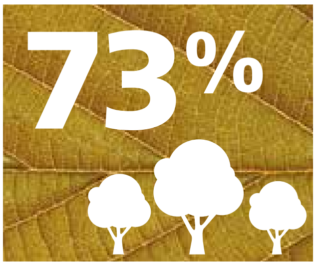
A high dominance value does not necessarily imply that these trees should form the core of any future planting strategy. Rather, it shows which species are currently delivering the most benefits based on their population and leaf area.

These species currently dominate the urban forest structure because they are the most abundant and have the largest leaf areas. They are therefore the most important in delivering existing benefits. However, future planting programmes should also take into account issues such as climate change and the likely built form of neighbourhoods, streets and new developments.

Larger trees have a greater functional value and provide increased benefits to the residents of Londoners (details of functional values and the resulting benefits are discussed later). It has been estimated in previous studies that a 75cm diameter tree can intercept 10 times more air pollution, can store up to 90 times more carbon and contributes up to 100 times more leaf area to the tree canopy than a 15cm diameter tree.

Leaf area provided by trees for each dbh class are illustrated for Inner, Outer and Greater London in fig 9 below.

Overall the total leaf[7] area provided by London's trees is 1,140km^2. Of which 239km^2 is provided by Inner and 900km^2 provided Outer London.



If the total leaf area of London's trees is expressed as a two-dimensional surface it would equal nearly 73% of the entire surface area of Greater London.

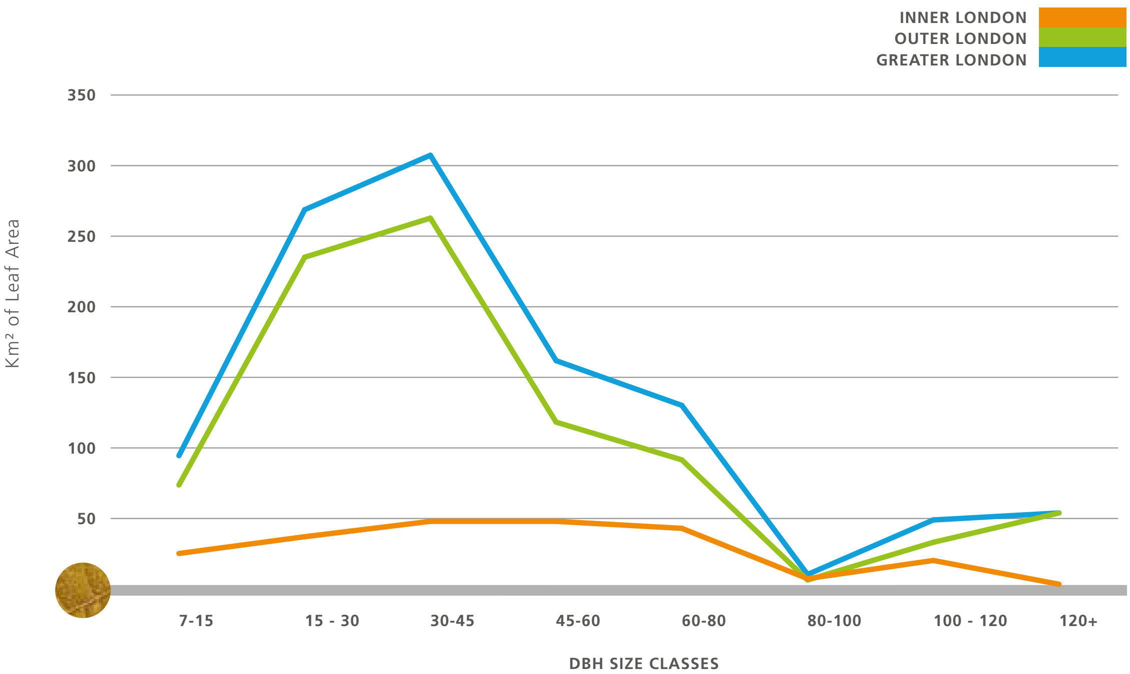


Fig 9. Leaf area (km2) provided by each dbh class for Inner, Outer and Greater London.

7 This includes all the leaves within the tree canopy and is not the same as the canopy cover discussed earlier. Whilst canopy cover is a top down estimate of ground which is covered by the tree canopy, leaf area is the total amount of all leaves within the three dimensions of the canopy if laid out flat in a two dimensional fashion.

Ecosystem Services - Air Pollution Removal

Air pollution caused by human activity has been a problem in our urban areas since the beginning of the industrial revolution; initially as a result of smoke from domestic and industrial chimneys, and latterly as exhaust emissions from the large numbers of vehicles on our streets.

The problems caused by poor air quality are well known, ranging from human health impacts to damage to buildings and smog.

Trees make a significant contribution to improving air quality by reducing air temperature (thereby lowering ozone levels), directly removing pollutants from the air, absorbing them through the leaf surfaces and by intercepting particulate matter (eg: smoke, pollen, ash and dusts). Trees can also indirectly help to reduce energy demand in buildings, resulting in fewer emissions from gas and oil fired burners, excess heat from air conditioning units and reduced demand from power plants.

The values for direct air pollution filtration by trees is given in table 5 page 34.

As well as reducing ozone levels, it is well known that a number of tree species also produce the volatile organic compounds (VOCs) that lead to ozone production in the atmosphere. The i-Tree software accounts for both reduction and production of VOCs within its algorithms. Although at a site specific level some trees may cause issues, the overall effect of London's trees reduces the production of ozone through evaporative cooling.

Pollutant	Tons removed per year			Value		
	Inner	Outer	Greater London	Inner	Outer	Greater London
Carbon monoxide (CO)	11	21	32	£10,360.00	£19,561.00	£29,921.00
Nitrogen dioxide (NO_2)	288	410	698	£28,433,674.00	£26,521,053.00	£54,954,727.00
Ozone (O_3)	86	911	997	£564,111.00	£5,947,607.00	£6,511,718.00
Particulates PM_{10}'s	105	194	299	£28,588,993.00	£34,679,430.00	£63,268,423.00
Particulates $PM_{2.5}$'s	43	110	153	£323,814.00	£825,666.00	£1,149,480.00
Sulphur Dioxide (SO_2)	28	34	62	£45,141.00	£57,038.00	£102,179.00

Table 5. Value of the pollutants removed and quantity per-annum within Inner and Outer London. Valuation method's used are UK social damage cost (UKSDC) where they are available - where there are no UK figures, the US externality cost (USEC) are used as a substitution.

Total pollution removal per ha in London is 2241 tons or 0.014 t/ha^{-1} yr^{-1}. These values are more than have been recorded by previous studies 0.009t ha^{-1} yr^{-1} for a site in London (PM_{10} only). In Glasgow[8] and Torbay pollution removal was recorded using i-Tree Eco as 0.050t ha^{-1} yr^{-1} and 0.0078t ha^{-1} yr^{-1} respectively.

A study in the West Midlands suggests that doubling tree cover across the region would reduce the concentration of fine PM_{10} particles by 25%. This could prevent 140 air pollution related premature deaths in the region every year[9].

Greater 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.

Pollution removal by trees in London is highest in the summer months (see fig 10 right). There is also greater leaf surface area during this period and therefore greater stomatal activity due to the increased day-light hours. It's worth noting that generally, pollution levels are also higher during this period of the year due to the weather patters during summer months, more high pressure, less wind and rain and therefore a longer dwell-time of pollutants.

8 Rumble et al 2015 / Torbay reference Rogers et al 2012
9 Stewart et al, (2003)

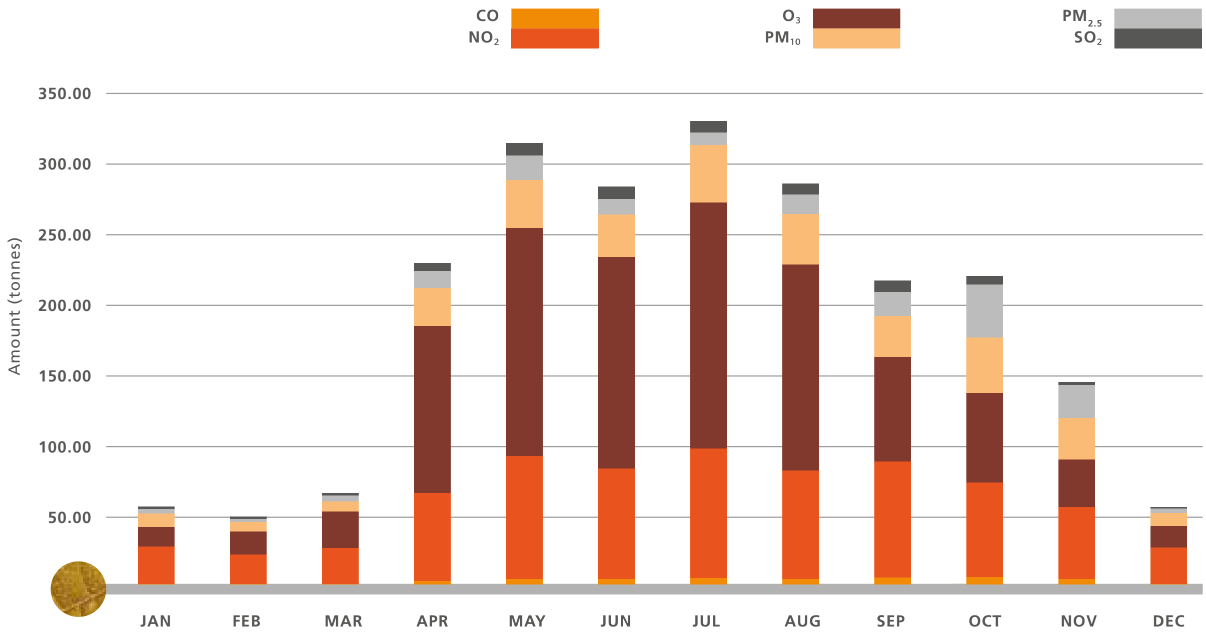


Fig 10. Monthly pollution removal.

Pollution removal was greatest for ozone. It is estimated that trees and shrubs remove 997 tons of air pollution ozone (O_3), 32 tons of carbon monoxide (CO), 698 tons of nitrogen dioxide (NO_2), 229 tons of particulate matter less than 10 microns (PM_{10}) and 153 tons of particulates less than 2.5 microns ($PM_{2.5}$) and 62 tons of sulphur dioxide (SO_2) per year with an associated value of over £ 126 million (based on estimated mean externality costs associated with pollutants and UK social damage costs published by the UK government[10]. The annual values are given in (table 5) opposite.

Road Transport Forecast

Forecasts from the Department for Transport's National Transport Model (DoT, 2013) up to 2040 predict that for the Strategic Road Network (SRN) from 2010 – 2040 traffic growth will be 46%.

This figure is subject to several key variables such as the price of oil and potential impacts will vary according to factors such as the take up of ultra–low emission vehicles such as electric cars.

It is also forecast that the levels of CO_2 will decline up to 2030 before slowly starting to rise again due to increased demand. This would imply a 15% reduction on 2010 CO_2 levels by 2040. Similarly road transport NO_2 and PM_{10} emissions from 2010 – 2040 are forecast to fall by 62% and 93% respectively with most of the reduction occurring before 2025.

Whilst the above predictions are positive in terms of pollution levels, this has to be put into context in that only a proportion of pollutants are absorbed at present and even if the predictions are correct vehicles using the network will still overall be a significant net producer of pollutants and an increasing shift to public transport, walking and cycling in cities such as London.

10 UK GOV, 2015

Ecosystem Services - Carbon Storage and Sequestration

Trees can help mitigate climate change by 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 carbon for decades or even centuries. Over the lifetime of a single tree, several tons of atmospheric carbon dioxide can be absorbed.

Carbon storage relates to the carbon currently held in trees tissue (roots, stem, and branches), whereas carbon sequestration is the estimated amount of carbon removed annually by trees. Net carbon sequestration can be negative if the emission of carbon from decomposition (dead trees) is greater than amount sequestered by healthy trees.

An estimated 2,367,000 tonnes (approximately 15t/ha) of carbon is stored in London's trees with an estimated value of £147 million[11]. Of this total 1,868,000 tonnes is stored in Outer London and 499,000 tonnes in Inner London.

11 Based on current carbon figures from DECC of £62 per ton

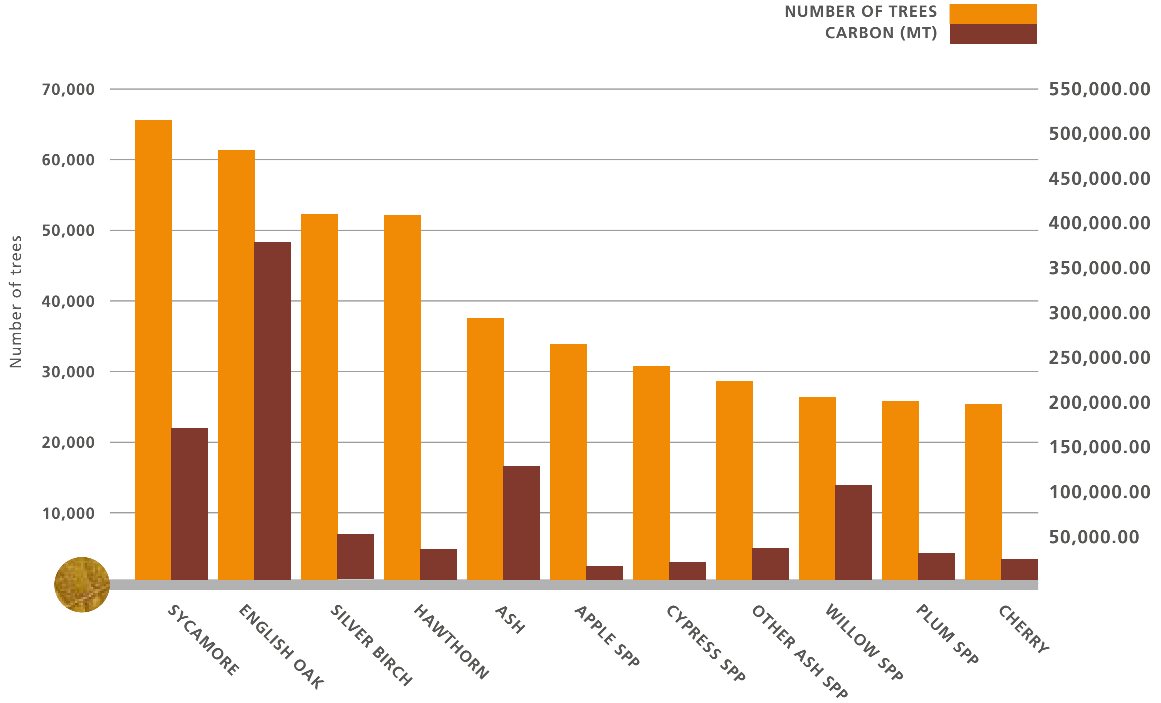


Fig 11. Ten most significant tree species and associated carbon storage.

As a species Oak stores the greatest amount of carbon within the urban forest (fig 11), equating to 481,795 tonnes. Together, the top ten trees store 78% of the city total.

Alternatively, the total carbon stored within London's trees is the equivalent to a sphere of carbon just over 1.3km in diameter. On the ground, this sphere would stretch from the centre of the Shard to St Pauls Cathederal (fig 12).

Carbon storage by trees is another way that trees can influence global climate change. As trees grow they store more carbon by holding it in their tissue. As trees die and decompose they release this carbon back into the atmosphere. Therefore the carbon storage of trees and woodland is an indication of the amount of carbon that could be released if all the trees died.

Maintaining a healthy tree population will ensure that more carbon is stored than released. Utilising the timber in long term wood products or to help heat buildings or produce energy will also help to reduce carbon emissions from other sources, such as power plants.

The gross sequestration of London's trees is about 77,198 tonnes of carbon per year. Allowing for dead and dying trees the net sequestration is estimated at 65,534 tonnes of carbon per year (approximately 2.4 t/yr/ha). The value of this sequestered carbon is estimated at 3.9 million pounds per year. This value will increase in a non linear fashion as the trees grow and as the social cost of carbon (its value per tonne) increases.

In Inner London the London plane, sycamore and oak are the most important trees in terms of carbon sequestration. In Outer London, sycamore, oak and silver birch are currently the most important trees in terms of carbon sequestration. Fig 12 below.

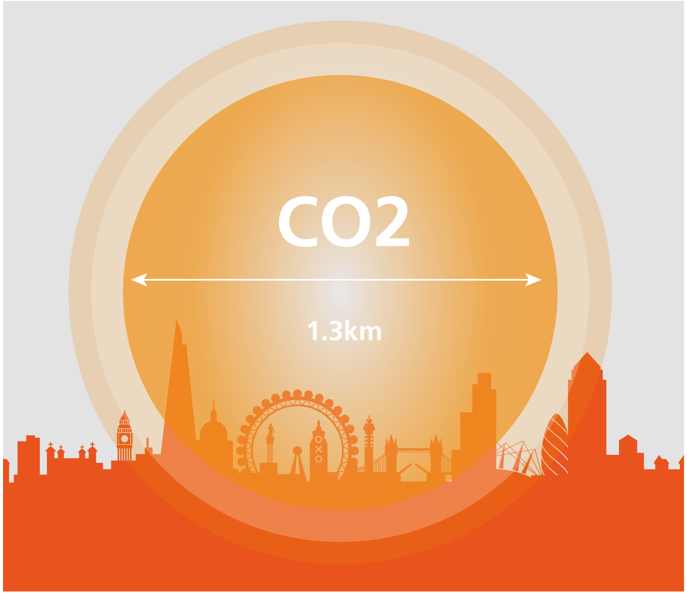


Fig 12. The carbon currently stored in London's urban forest equates to a gigantic sphere of carbon 1.3km in diameter.

Trees also play an important role in protecting soils, which is one of the largest terrestrial sinks of carbon. Soils are an extremely important reservoir in the carbon cycle because they contain more carbon than the atmosphere and plants combined[12].

Fig 13 (right) provides a breakdown of carbon stored and sequestered across Inner, Outer and Greater London.

Carbon storage and sequestration depends not only on the number of trees present, but also their characteristics. In this case, the mass of a tree is important, as larger trees store more carbon in their tissues. London Plane, for example, makes up just 1.4% of the tree population but stores 6% of the total carbon, apple on the other hand, stores only 0.8% of carbon but makes up 4% of the tree population.

The gross amount of carbon sequestered by the urban forest in London each year is estimated at 77,200 tonnes.

The carbon stored and sequestered by trees can be valued within the framework of the UK government's carbon valuation method[13]. This is based on the cost of the fines that would be imposed if the UK does not meet carbon reduction targets. These values are split into two types, traded and non-traded. Traded values are only appropriate for industries covered by the European Union Emissions Trading Scheme. Tree stocks do not fall within this category so non-traded values are used instead. Within non-traded values, there are three pricing scenarios: low, central and high. These reflect the fact that carbon value could change due to outer circumstances, such as fuel price.

Area	Carbon Stored (tonnes)	Value	Carbon Sequestration 2014(tonnes)	Value
Inner London	499,000	£29.9 million	15900	£955,000
Outer London	1,868,000	£112 million	61300	£3.68 million
Greater London	2,367,000	£142 million	77200	£4.63 million

Table 6. Comparison of carbon stored and sequestered.

12 Ostle et al, (2009).

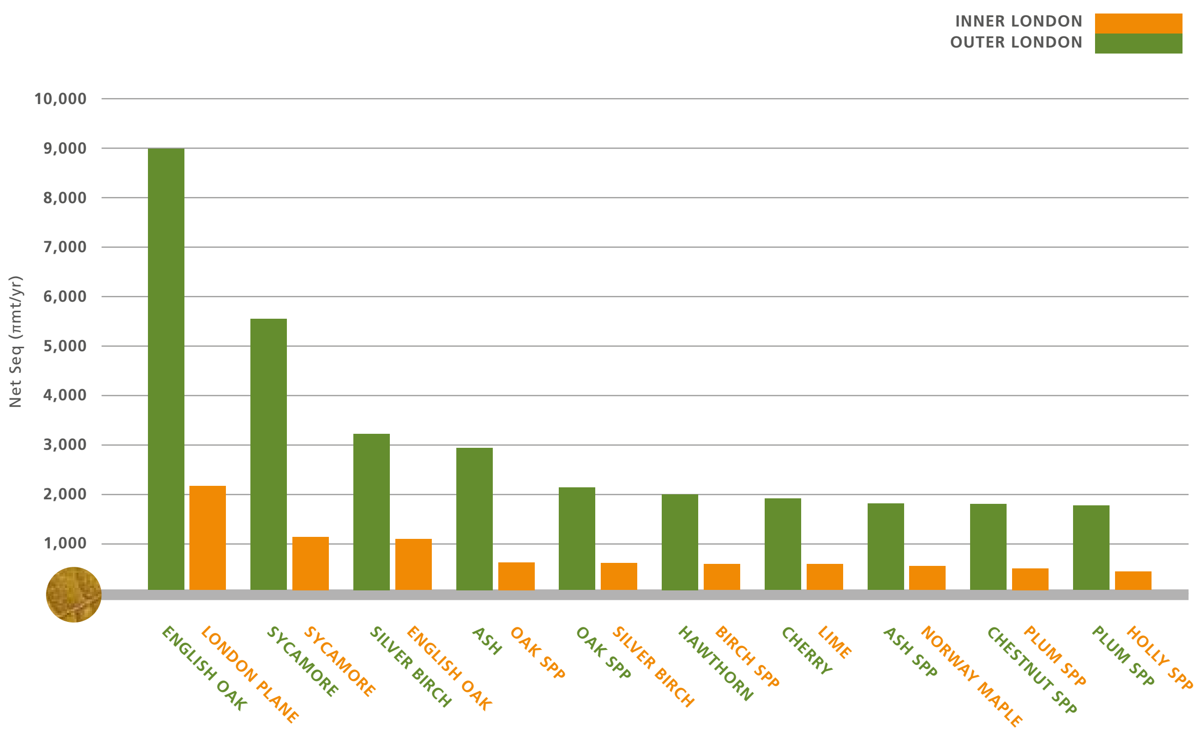


Figure 13. Amount of carbon sequestered by the top ten trees in London's urban forest (Inner London in grey and Outer London in green).

13 DECC, (2014)

Ecosystem Services - Stormwater Runoff

Surface water flooding occurs when rainfall runs off land and buildings at such a rate that it is unable to drain away in streams, rivers, drains or sewers. It is therefore distinct from river flooding or tidal flooding where rivers or the sea breach river/sea walls and defences.

In London about 80,000 properties are at risk from deep (>0.5m) surface water flooding[14]. Additionally, the water quality in London's rivers and lakes mostly ranges from 'moderate' to 'poor' with only a handful classed as 'good'[15]. Surface water run off regularly causes sewer overflow and untreated sewage going straight into the Thames.

Large urban areas are particularly at risk because the coverage of impermeable surfaces such as buildings, pavements, roads and parking areas means that rainwater cannot permeate into the ground or be absorbed by plants and trees or stored in ditches and ponds.

In addition this runoff can quickly become polluted as the rain effectively washes urban streets and buildings carrying high concentrations of hydrocarbons, metals, dust, litter and organic materials into local streams and rivers where the concentration can cause serious pollution to those watercourses.

Climate change predictions suggest that we will see more intense rainfall events during summer months, and generally wetter conditions through winter months which will intensify the problems.

14 London's Environment Revealed 2011
15 http://environment.data.gov.uk/catchment-planning/ManagementCatchment/35/Summary

Nearly 40% of the surface area in Greater London is impermeable covered with either, tar, concrete or buildings (page 24). The infrastructure required to remove surface water from towns and cities is costly and much of this infrastructure dates from Victorian times.

During rainfall a proportion of the precipitation is intercepted by vegetation (trees and shrubs) whilst a further proportion reaches the ground. Precipitation that reaches the ground that does not or cannot infiltrate into the soil becomes surface water runoff.

Furthermore, their root systems promote infiltration and water storage in the soil. Together this slows the passage of stormwater into the piped drainage network.

Greater London has a total tree population of approximately 8.5 million trees with a leaf area of some 1047km². The effect of this leaf area is to produce an avoided runoff of some 3,414,000 cubic metres per year. This is almost the equivalent of the 10 times the volume of water in the London Serpentine (which holds approximately 393,700 cubic metres of water) or 1365 olympic swimming pools. This avoided runoff has a value to Greater London of £1.5 million (see fig 14 page 42).

The variance between Inner and Outer London is large. Inner London has 1,587,205 trees, avoided runoff of 705,000 cubic metres and a value of £568,935 while Outer London has 683,3979 trees, avoided runoff of 2,709,000 cubic metres with a value of £2.2 million.

The amount of run off also varies with the proportion on impermeable surfaces. There is a small variation of 10% between Inner London (48.9%) and Outer London (36.8%).

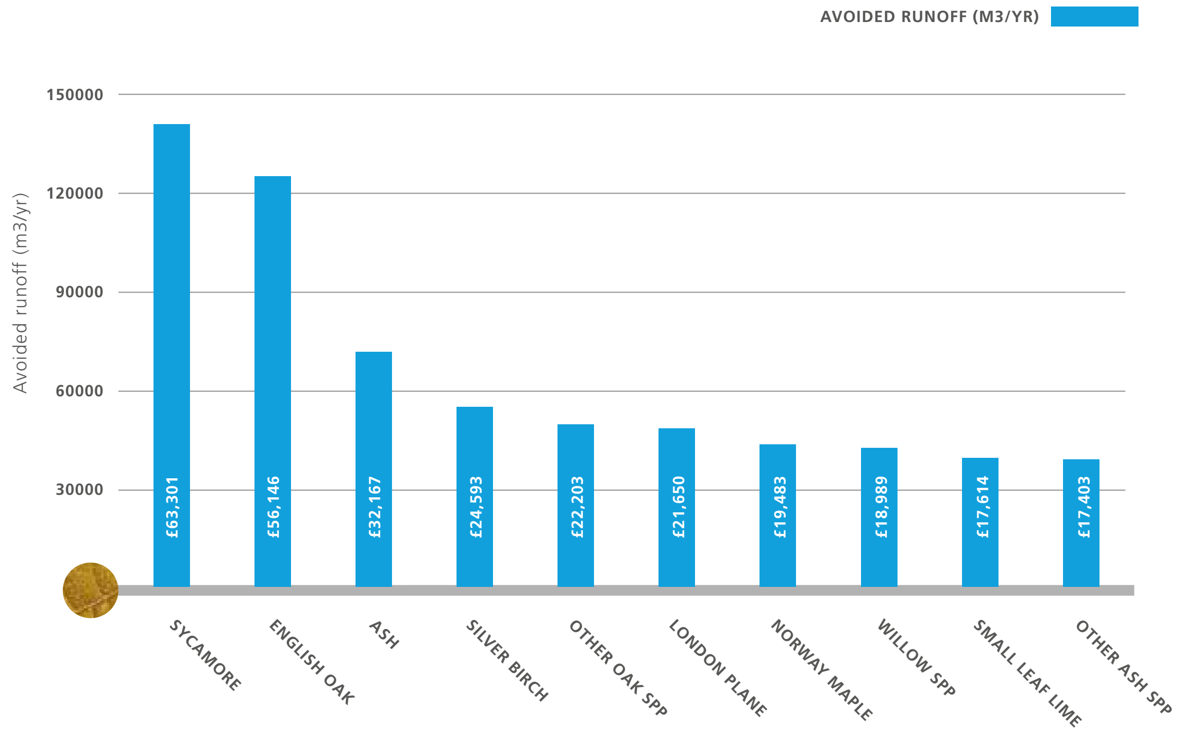


Fig 14. Avoided runoff from the top ten trees.

It is interesting to note that Inner London has a lower avoided run off due to there being less tree canopy yet a higher need because of the larger area of impermeable surface.

Sycamore (*Acer psuedoplatanus*), English Oak (*Quercus Robur*) and Silver Birch (*Betula pendula*) are the three most common species across London. These three species have a combined leaf area of 268km², this is equivalent 23% of the total leaf area. It represents some 1.8 million individual trees with a combined avoided runoff of 320729m³. These three species alone contribute £258,828 in value of avoided run off. This equates to £966 for every 1km² of leaf area.

For the avoided runoff of the top 10 species throughout London see table 7 right.

Area	Number of Trees	Leaf Area (km²)	Avoided Runoff (m³/yr)	Value (£)
Inner London	1,587,205	217	704,785	310,105
Outer London	6,833,979	830	2,708,686	446,976
Greater London	8,421,184	1,047	3,413,471	1,191,821

Table 7. Comparative values for avoided runoff by each land function type.

Ecosystem Services - Buildings and Energy Use

Trees affect energy consumption by shading buildings, shielding from winter winds and regulating temperatures through evapotranspiration. 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 location of trees around the building.

i-Tree Eco models tree position, orientation and distance relative to buildings to determine the impact of the urban forest on the energy use by buildings, namely on heating and air-conditioning.

This model component is designed for US climate types, building types and efficiency characteristics, heating fuel types and mixes, energy production methods and emission factors. Eco is capable of generating energy effect estimates for the UK, although the tool has its limitations as selecting and adapting a climate region in the US also means that the typical building and energy information are applied to some extent. Further research is needed into better adapting the US model to UK realities in order to provide more accurate results in the future.

The analysis thus provides an indication of the likely impact of urban trees across London on energy use by buildings, and the results are presented in Table 8, as units of energy saved, and in Table 9, as savings in pounds.

		Heating	Cooling	Total
Inner London	MBTU	-47,221	-	**-47,221**
	MWH	-2,613	8,560	**5,947**
	Carbon avoided (mt)	-806	1,186	**380**
Outer London	MBTU	-113,561		**-113,561**
	MWH	-6,715	17,671	**10,956**
	Carbon avoided (mt)	-1,949	2,451	**502**
Greater London	MBTU	-160,782		**-160,782**
	MWH	-9,328	26,231	**16,903**
	Carbon avoided (mt)	-2,755	3,637	**882**

Table 8. Annual energy effects of trees near buildings.

		Heating	Cooling	Total
Inner London	MBTU	-£664,086.00		**-£664,085.00**
	MWH	-£389,859.00	£1277,152.00	**£887,292.00**
	Carbon avoided	-£49,980.00	£73,543.00	**£23,564.00**
	Total	**-£1,103,925.00**	**£1,350,695.00**	**£246,770.00**
Outer London	MBTU	-£15,959,130.11	-	**-15,959,130.11**
	MWH	-£1,001,878	£2,636,513	**£1,634,635**
	Carbon avoided	-£120,857	£151,987	**£31,129**
	Total	**-£2,719,784**	**£2,788,450**	**£68,715**
Greater London	MBTU	-£2,261,134		**-£2,261,134**
	MWH	-£1,391,737	£3,913,665	**£2,521,927**
	Carbon avoided	£170,810	£225,494	**£54,684**
	Total	**-£3,823,682**	**£4,139,159**	**£315,477**

Table 9: Annual costs and savings due to trees near buildings (in pounds).

Energy costs and savings are calculated based on the value of £149.20 per MWH and £14.06 per MBTU. Carbon avoided values are calculated based on £62 per metric ton.

Trees in London are thus estimated to reduce energy-related costs from buildings by almost £315,477 million annually. Trees also provide an additional £52,920 in value by reducing the amount of carbon released by fossil-fuel power plants (a reduction of 882 metric tons of carbon emissions).

With respect to buildings' use of energy for heating, trees that shelter buildings from the prevailing wind offer energy savings. However, trees planted to the south can shade a building, resulting in more energy being required for heating, especially where the canopy is dense and the height to canopy base is low, restricting wintertime sun from warming the building. This explains the negative results for heating in London.

With respect to buildings' use of energy for cooling, trees planted to the west and east can partially block incoming solar radiation, thus reducing air-conditioning usage in the warmer months.

To learn more about the energy effects of trees, to further increase the role of trees in supporting efficient use of energy and to limit planting that may have a negative impact on energy use by buildings, homeowners and developers can follow guidelines on the strategic placement of trees around buildings[16].

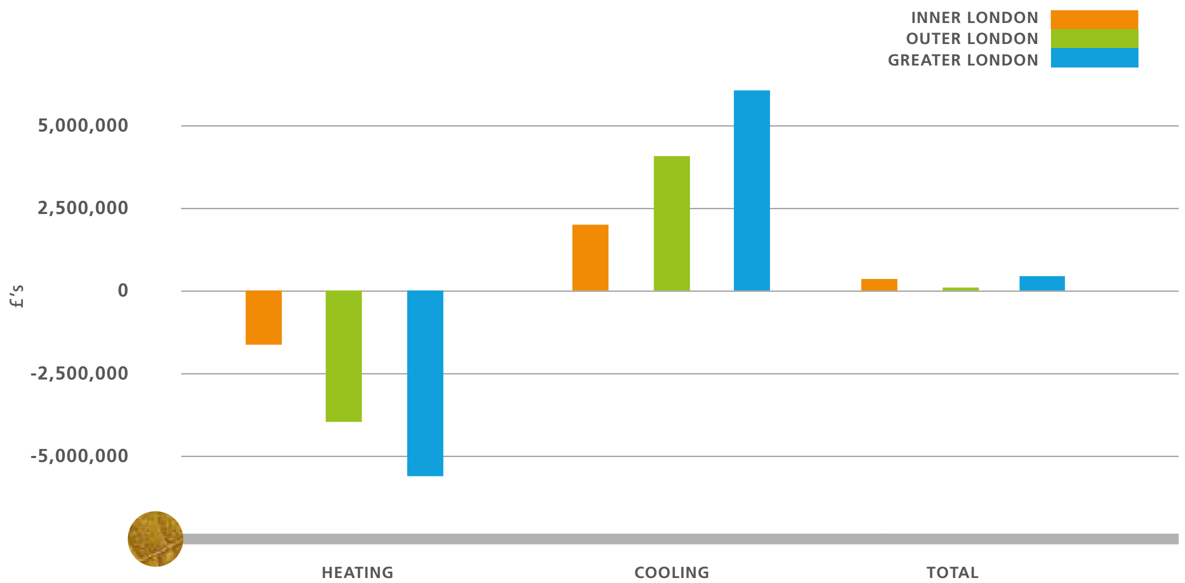


Fig 15. Annual costs and savings due to trees near buildings (in pounds).

16 McPherson and Simpson, (1999)

Tree Diversity

Diversity in the urban forest has two main components, the number of species present and the genetic diversity of the individual species present. This diversity reduces the potential impact from threats such as pest and disease and climate change and increases the capacity of the tree population to deliver ecosystem services.

Within the urban forest patterns of diversity vary with biophysical and socioeconomic factors[17] and also by land use[18].

Although i-Tree Eco does not yet calculate a valuation of bio diversity[19] it does provide an in-dication of the tree species diversity using various diversity indexes (Shannon, Simpson and Menhinick). The Shannon diversity index is the most appropriate as it has a low sensitivity to sample size and results for Greater London are outlined in table 10 below.

Area	Species	Species/ha	Shannon Index
Inner London	71	9.97	3.67
Outer London	103	5.43	3.75
Greater London	126	4.83	3.92

Table 10. Tree diversity indexes for London.

Notes for Table 10
Spp: is the number of species sampled
Spp/ha: is the number of species found per hectare of area sampled
SHANNON: Is the Shannon–Wiener diversity index, which assumes that all species within the area have been sampled. It is an indicator of species richness and has a low sensitivity to sample size.

17 Escobedo et al., 2006, Kendal et al., 2012
18 Pauleit et al., 2002, Saebo et al., 2003, Sjoman and Busse Neilson, 2012
19 Challenges exist in valuing biodiversity because it is difficult to identify and measure the passive, non-use values of biodiversity (Nunes and van de Bergh, 2001)

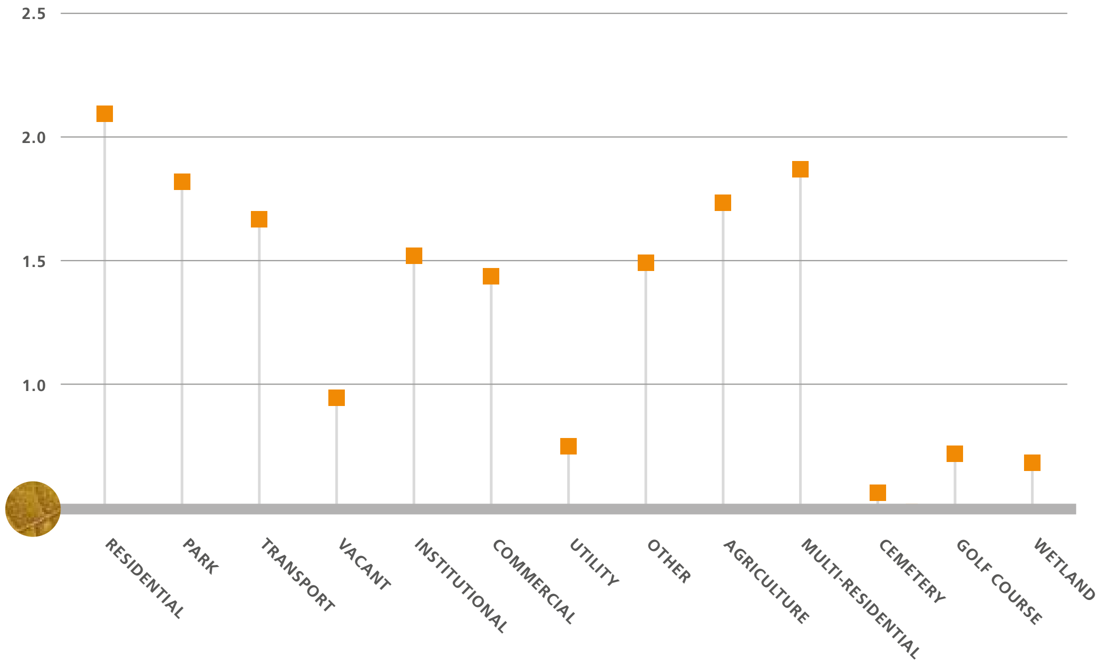


Fig 16. Shannon Diversity by Land Use.

Diversity is important because the diversity of species within London (both native and non-native) will influence how resilient the tree population will be to future changes, such as mini-mising the overall impact of exotic pests, diseases and climate change.

A total of 126 different species were sampled in Greater London with approximately 4.83 species per hectare. As might be expected, a greater number of species were sampled in Outer London (103) than in Inner London (71) although the different species per hectare were greater in Inner London (9.97) than that found in Outer London (5.43).

On the Shannon diversity index (where 1.5 is considered low and 3.5 is high) both Inner Lon-don (3.66) and Outer London (3.75) demonstrated a high level of species diversity. Using the same index both Inner and Outer London showed higher levels of species than other compa-rable studies carried out in the UK, Torbay (3.32), Edinburgh (3.2), Glasgow (3.3), and Wrexham (3.1).

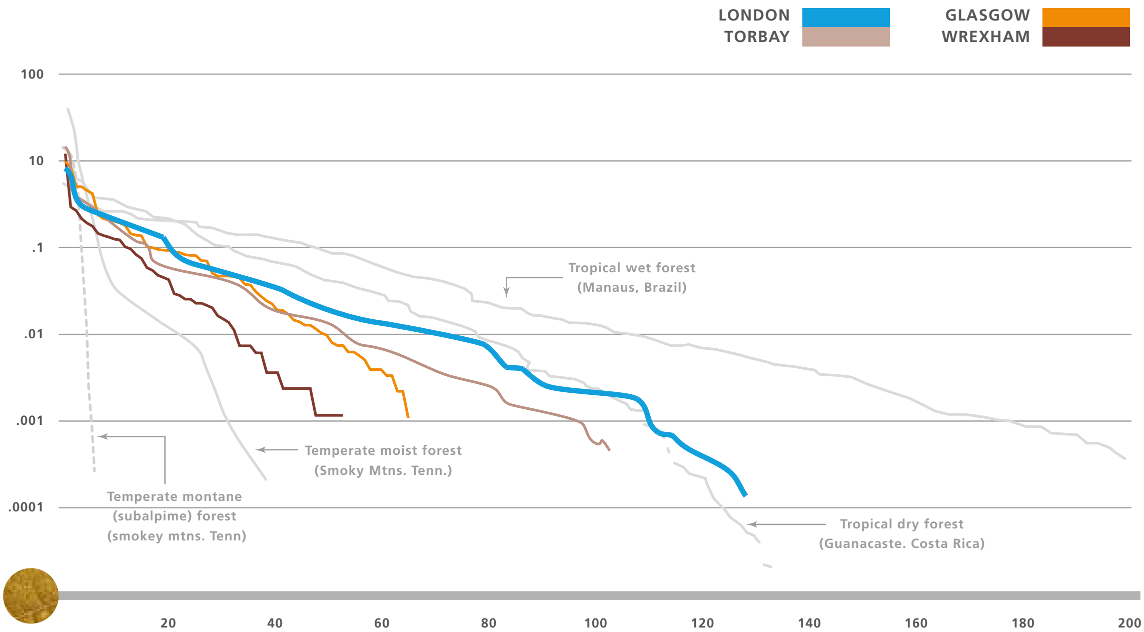
With regard to species diversity and their dominance within the population London has one of the most diverse tree-scapes yet recorded in the UK using i-Tree Eco (see fig 16 below). When compared to other natural forest types London's Urban Forest compares well to both these and other Urban Forests which have been sampled using the i-Tree Eco methodology.

However, species diversity is only one part of the equation. Approximately 21% of London's tree population is comprised of species which are clonal selections, the significance of which means that as they are genetically identical they are therefore more vulnerable to the ingress of a particular pest and/or disease.

Fig 17. London's Dominance Diversity Curve compared with Natural forest types (Hubble, 1970) and diversity in other i-Tree Eco studies (Frediani and Rogers (in press)). On the Y axis is the relative im-portance or dominance of the species, on the X axis is the number of species (represented by each point). A steep curve with less points shows a tree population which is less diverse and dominated by fewer species such as subalpine forests. A shallow curve (such as in a tropical forest) shows a tree population which is diverse and where more species equally dominate. London's urban forest (in Blue) is the most diverse urban forest yet recorded in the UK using i-Tree.

While samples revealed a high diversity of species in both Inner and Outer London the distribution (and therefore diversity) of trees varied according to the land use types sampled (see fig 17 below).

In Inner London the greatest diversity of trees were found on residential and multi-residential land, followed by parks, agriculture and transportation land uses. Cemeteries, Golf courses, Wetland and Utilities were areas in which the lowest tree diversity was encountered.



Habitat Provision

London's trees are a key component of our valuable urban habitat and make up a significant and highly visible component of the capital's biodiversity (with many sites accordingly designated for their biodiversity value). They include ancient semi-natural and secondary native woodland, wood pasture, parkland, scrub, and individual veteran trees.

Some species, such as Black poplar are a biodiversity priority and many other priority species including bats, common dormouse, stag beetle, juniper, bluebell, coralroot, oak lutestring moth, hawfinch, and spotted flycatcher are directly associated to trees and/or woodland habitat.

Some species in the capital subject to legal protection are strongly associated with trees and woodland. These include all bats (at least 9 species in Greater London), badger, purple emperor, white-letter hairstreak, stag beetle, and oak polypore. Special protection also applies to a range of birds including hobby, barn owl, firecrest, and addition to that applied to all breeding birds (many of which nest in trees and shrubs) (Greater London Authority, 2005).

Trees and shrubs also provide food for many animal, plant and fungi species, from non-vascular plants, such as mosses, to insects, birds and mammals. Two examples are included in this section to highlight some of the organisms that trees can support: i) the importance of trees/shrubs for supporting insects generally, and ii) the importance of trees/shrubs to pollinators. For a broader review see Alexander et al. (2006).

Species	Tree / Shrub	Season
Apple spp	Tree	Spring
Bay tree spp	Shrub	Summer
Blackthorn	Tree	Spring
Cherry laurel, common	Shrub	Spring
Common apple	Tree	Spring
Common plum	Tree	Spring
Cotoneaster (genera)	Shrub	Spring
Goat willow	Tree	Spring
Hawthorn, common	Tree	Spring, Summer
Hedge maple	Tree	Spring
Holly, common	Tree	Spring, Summer
Horsechestnut	Tree	Spring
Laurustinus	Shrub	Winter
Plum spp	Shrub	Spring
Rowan, common	Tree	Summer
Small-leaved lime	Tree	Summer
Sycamore	Tree	Spring
Wild cherry	Tree	Spring
Willow (genus)	Shrub	Spring

Table 11. Trees and shrubs encountered in the London survey that are beneficial to pollinators (RHS 2012).

Pollinating insects provide ecosystem services in urban areas by pollinating flowers and producing food. The diverse nature of urban land use offers a wide range of pollinator habitats but trees offer an important source of pollen at particular times of year when other sources are unavailable. In London, twenty of the tree genera found in the survey support pollinating insects (RHS 2012) (Table 11).

Many insect herbivores are supported by trees and shrubs. Some specialise on just a few tree species, whilst others are generalists that benefit from multiple tree and shrub species. Of the species found in London, native willows, oaks and birches support the most varied insect herbivore species (fig 18). Beetles, although supported by these species are better supported by Scots pine (Table 11), highlighting that some species are extremely important for certain groups.

Non-native trees associate with fewer species than native trees as they have had less time to form associations with native organisms (Kennedy & Southwood 1984), In urban areas those associations may be more limited and some non-native trees such as sycamore support a large quantity of biomass with benefits such as food source for birds. In addition, some native species form few insect herbivore associations due to their high level of defence mechanisms, yew being a good example (Daniewski et al. 1998). However, these species may support wildlife in other ways, for example by supplying structural habitat dead wood.

The number of species of insects associated with British trees: a Re-analysis (Kennedy and Southwood)								
Species	Scientific name	Total	Beetles	Flies	True bugs	Wasps and sawflys	Moths and butterflies	Other
Willow (3 spp)	Salix (3 spp.)	450	64	34	77	104	162	9
Oak (English and Sessile)	Quercus petrea and robur	423	67	7	81	70	189	9
Birch (4 spp)	Betula (4 spp)	334	57	5	42	42	179	9
Common Hawthorn	Crataegus monogyna	209	20	5	40	12	124	8
Poplar (3 spp)	Populus (3 spp)	189	32	14	42	29	69	3
Scots Pine	Pinus sylvestris	172	87	2	25	11	41	6
Blackthorn	Prunus spinosa	153	13	2	29	7	91	11
Common Alder	Alnus glutinosa	141	16	3	32	21	60	9
Elm (2 spp)	Ulmus (2 spp)	124	15	4	33	6	55	11
Hazel	Corylus avellana	106	18	7	19	8	48	6
Common Beech	Fagus sylvatica	98	34	6	11	2	41	4
Norway Spruce	Picea abies	70	11	3	23	10	22	1
Common Ash	Fraxinus excelsior	68	1	9	17	7	25	9
Mountain Ash	Sorbus aucuparia	58	8	3	6	6	33	2
Lime (4 spp)	Tilia (4 spp)	57	3	5	14	2	25	8
Field Maple	Acer campestre	51	2	5	12	2	24	6
Common Hornbeam	Carpinus betulus	51	5	3	11	2	28	2
Sycamore	Acer pseudoplatanus	43	2	3	11	2	20	5
European Larch	Larix decidua	38	6	1	9	5	16	1
Holly	Ilex aquifolium	10	4	1	2	0	3	0
Horse Chestnut	Aesculus hippocastanum	9	0	0	5	0	2	2
Common Walnut	Juglans regia	7	0	0	2	0	2	3
Yew	Taxus baccata	6	0	1	1	0	3	1
Holm Oak	Quercus ilex	5	0	0	1	0	4	0
False Acacia	Robinia pseudoacacia	2	0	0	1	1	0	0

Table 12. Numbers of insect species supported by tree species (a) encountered in the London study and (b) for other commonly found urban tree species for which data is available#. Brightest green boxes denote the highest number of species supported in that insect group and red denote the lowest number. Middle values are represented by a gradient between the two.

Data from Southwood (1961) and Kennedy and Southwood (1984)

	Scientific name	Total	Beetles	Flies	True bugs	Wasps and sawflys	Moths & butterflies	Other
(a) Species								
Willow (3 spp)	Salix (3 spp.)	450	64	34	77	104	162	9
Oak (English and Sessile)	Quercus petrea and robur	423	67	7	81	70	189	9
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Sycamore	Acer pseudoplatanus	43	2	3	11	2	20	5
European Larch	Larix decidua	38	6	1	9	5	16	1
Holly	Ilex aquifolium	10	4	1	2	0	3	0
Horse Chestnut	Aesculus hippocastanum	9	0	0	5	0	2	2
Common Walnut	Juglans regia	7	0	0	2	0	2	3
Yew	Taxus baccata	6	0	1	1	0	3	1
Holm Oak	Quercus ilex	5	0	0	1	0	4	0
False Acacia	Robinia pseudoacacia	2	0	0	1	1	0	0
(b) Species								
Crab Apple	Malus sylvestris	118	9	4	30	2	71	2
Juniper	Juniperis communis	32	2	5	7	1	15	2
Spruce (spp)	Abies spp	16	8	0	5	0	3	0
Sweet Chestnut	Castanea sativa	11	1	0	1	0	9	0

Fig 18. Relative importance of trees found in the London survey for supporting insects. Where multiple tree species are denoted (in parentheses), insect species reflect the total associated with all hosts. Data from Southwood (1961) and Kennedy and Southwood (1984).

Pest and Disease Impacts

Pest and diseases are a serious threat to urban forests. The impact of climate change is changing and extending the range of pest and disease which are likely to affect the UK. This is exacerbated by the continued importation of trees, particularly large landscape trees, from across Europe and elsewhere and compounded by the ever increasing range of packaging materials used in international trade.

Severe outbreaks have occurred within living memory with Dutch Elm Disease killing approximately 30 million Elm trees in the UK.

The potential impact of pest and diseases may vary according to a wide variety of factors such as tree health, local tree management and individual young tree procurement policies. The weather also plays a significant role. In addition pest and diseases may occur most frequently within a particular tree family, genus or species.

A tree population that is dominated by a few species is therefore more vulnerable to a significant impact from a particular disease than a population which has a wider variety of tree species present. One of the prime objectives of any urban forestry management programme should be to facilitate resilience through population diversity.

Fig 19 (right) illustrates the percentage species susceptibility to these identified threats. Fig 20 (page 55) illustrates the potential cost of an outbreak by the pathogens investigated.

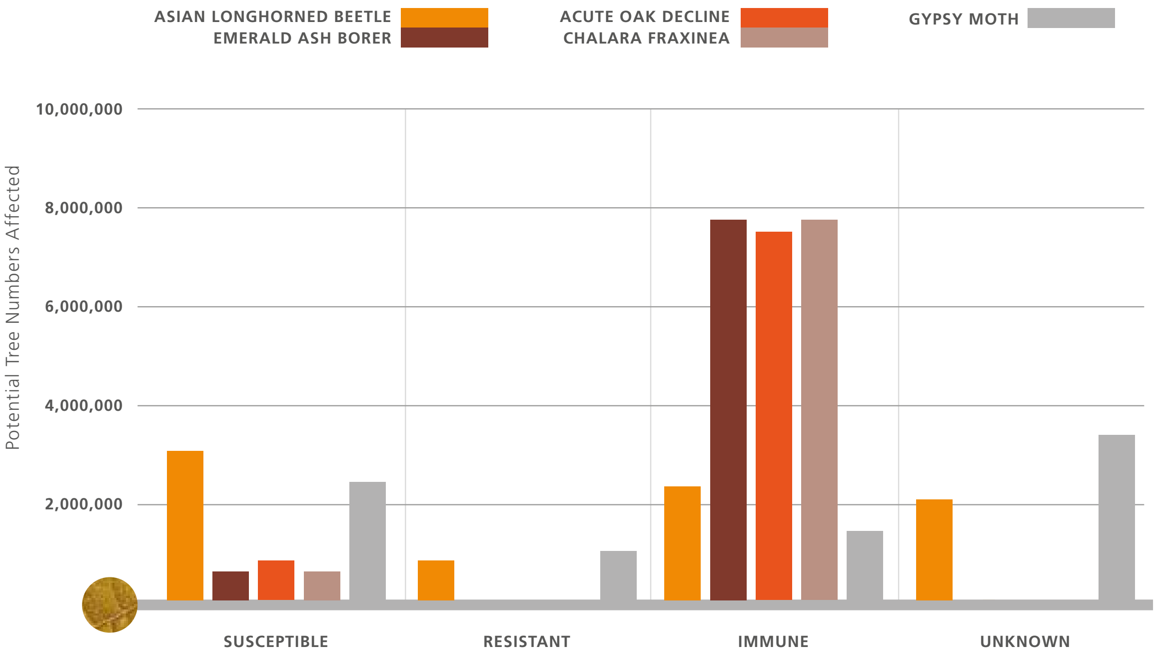

Fig 19. Potential impacts of the identified pathogens.

Acute Oak Decline

There have been episodes of 'oak decline' documented for almost 100 years and it is regarded as a complex disorder whereby typically several damaging agents interact. The outcome results in high levels of mortality but trees can also recover. The most recent episodes of Acute Oak decline have occurred predominantly in the South East and Midlands but is distribution has slowly intensified and spread to include Wales and East Anglia with occasional occurrences in the South West. The population of Oak in Greater London is approximately 911,900 trees and this represents over 10% of the total population.

Asian Longhorn Beetle

Asian Longhorn Beetle is a native of SE Asia where is kills many broadleaved species. In America Asian Longhorn Beetle has established populations in Chicago and New York where damage to street trees can only be managed by high levels of felling, sanitation and quarantine. It is estimated by the United States Department of Agriculture and Forest Service that unless the spread of the beetle is contained up to 30% tree mortality could result.

To date the beetle has been found in the UK during the inspections of incoming packaging at several ports and a small population established in Kent in 2012 was located and removed by the Forestry Commission and the Food and Environment Research Agency.

The known host species include the following tree species:
Acer spp **(Maples and Sycamore)**
Aesculus **(Horse Chestnut)**
Albizia **(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
Platanus spp **(Plane)**
Populus spp **(Poplar)**
Prunus spp **(cherry/plum)**
Robinia psuedoacacia **(false acacia/black locust)**
Salix spp **(willow)**
Sophora spp **(Pagoda tree)**
Sorbus spp **(Mountain ash/ rowan/whitebeam.)**
Quercus palustris **(American pin Oak)**
Quercus rubra **(North American red Oak)**
Ulmus spp **(Elm)**

It is estimated that an infestation of Asian Longhorn Beetle in Greater London could impact on some 3.8 million trees which represents 31% of the total tree population. Replacing these trees would cost £23 Billion.

Chalara fraxinea

Ash dieback is caused by the fungus *Chalara fraxinea*. It induces vascular wilt, targeting common and narrow leaved Ash, which results in dieback and death. It is thought to have been introduced into Europe in 1992 and was first discovered in the UK on a nursery in 2012. Since being found in the UK the rate of infection has increased at a steady rate and has now been found in over 900 locations, especially in the South East.

Although initially found in newly planted ash populations by the summer of 2014 infected trees were being found within established populations, including trees in urban areas and in the wider environment.

Ash represents just over 7% of the tree population of Greater London with an estimated 657,950 trees.

Emerald Ash Borer

There is no evidence to suggest that Emerald ash Borer is present in the UK. It is present in Russia and is moving West and South at a rate of 30-40km each year. A native of Asia it is thought that the beetle has been introduced to new countries on imported packaging material. It has caused the death of millions of Ash trees in the United States and once established has proved difficult to contain.

The species which would be effected are the same as for Chalara above. To replace these trees would cost £5.6 Billion.

Gypsy Moth

Gypsy Moth is a serious pest causing significant defoliation to oak trees, but also to species such as hornbeam, beech, chestnut, birch and poplar. It can cause death if serious defoliation occurs on a single tree. Breeding colonies persist in Aylesbury, Buckinghamshire and north east London. It has been present in the UK since 1995 with all known sites subject to an extensive pheromone based trapping programme managed by the Forestry Commission.

In addition the moth has urticating hairs which can cause severe allergic reactions to humans.

The potential host species named above account for some 2.5 million trees within the Greater London tree population. This represents approximately 21% of the total tree population. To replace these trees would cost £2.1 Billion.

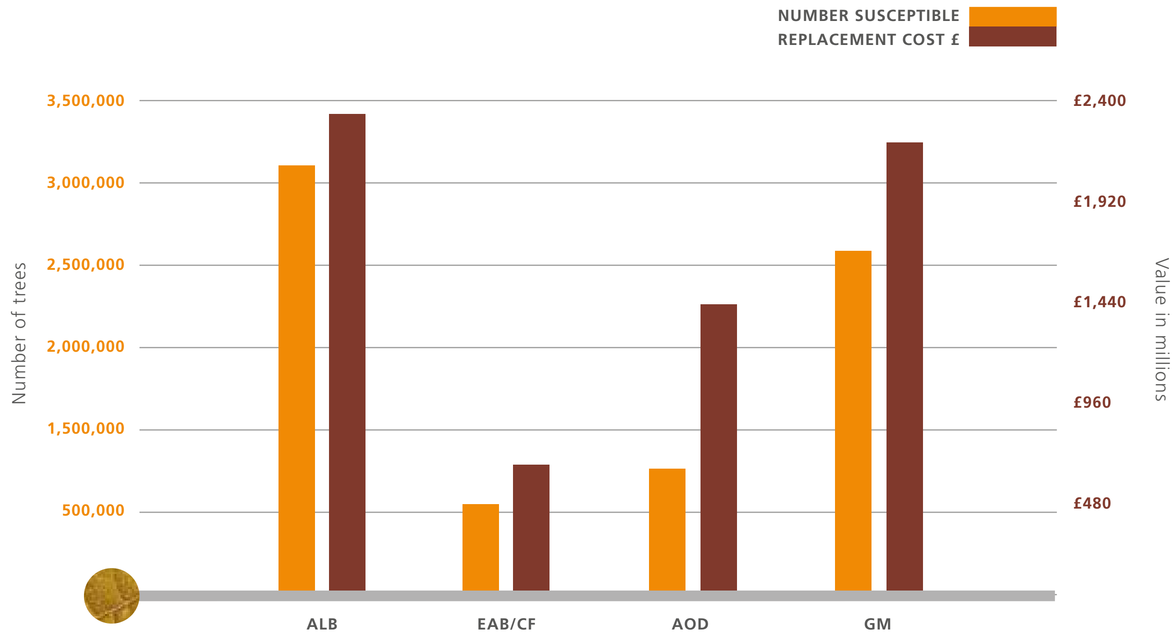

Fig 20. Potential number of trees affected by pathogens and the cost of replacement.

Plane Wilt

Ceratocystis fimbriata f.platani originates in the United States and causes canker stain on London plane and it's parents P. orientalis and P occidentalis. The pathogen was imported to a number of European ports during World War II on infected crating material and has spread rapidly through Switzerland and Italy. Its progress through France has been slower but reports indicate that it is moving northwards at a much faster rate than in previous decades.

The fungus causes severe wilting and mortality. It has yet to be identified as present in the UK. In Lyon in France the wilt is present and the only control measures available are felling and destruction and a reduction in the number of Plane trees planted.

The fungus produces resilient long lived spores which survive in the soil but the main method of transfer is through human activity and the planting of plane imported from affected areas.

In Greater London there are 121,000 plane trees and although these represent just 1.43% of the total tree population their canopy cover (2.5% Outer and 8.9% Inner London) accounts for making this a significant tree in London's tree scape. To replace these trees would cost somewhere in the region of £3.5 Billion.

One of the key factors in assessing the vulnerability of the resilience of a tree to pest and disease is the overall condition of that population. Tree condition was measured as part of this survey and fig 21 below shows the overall health of the trees in London.

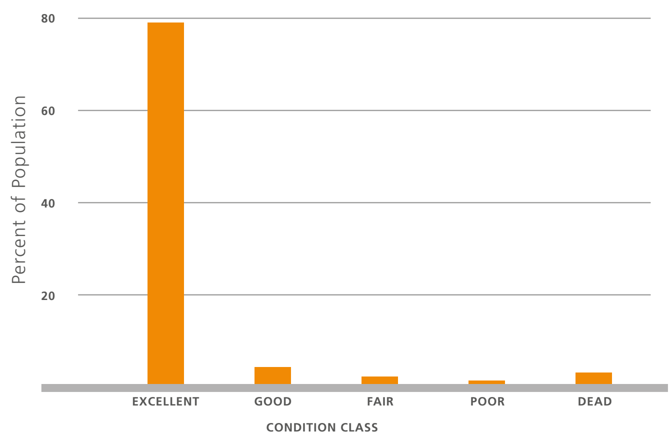

Fig 21. Overall tree condition.

Just over 86% of the trees assessed in Greater London were considered to be in to be in either excellent or good condition exhibiting less than 5% dieback. In Inner London this percentage fell slightly to 83% while Outer London the percentage was 87%.

However, the percentage of trees considered in excellent condition varied between Inner London (63%) and Outer London (77%) The percentage of trees considered dead or dying was 3.6% for Greater London as a whole with little difference between Inner and Outer London.

Of the three most common species across Greater London, Sycamore (*Acer psuedoplatanus*) 81%, English Oak (*Quercus robur*) 85% and Silver Birch (*Betula pendula*) 88% were considered to be in excellent or good condition.

Across Greater London only Pine (*Pinus spp*) 19%, Black Locust (*Robinia psuedoacacia*) 37.5% Common Apple (*Malus spp*) 33%, Leyland cypress (*Cupressus leylandii*) 17.4%, and Kanzan cherry (*Prunus Kanzan*) 25% were considered to be in poor condition.

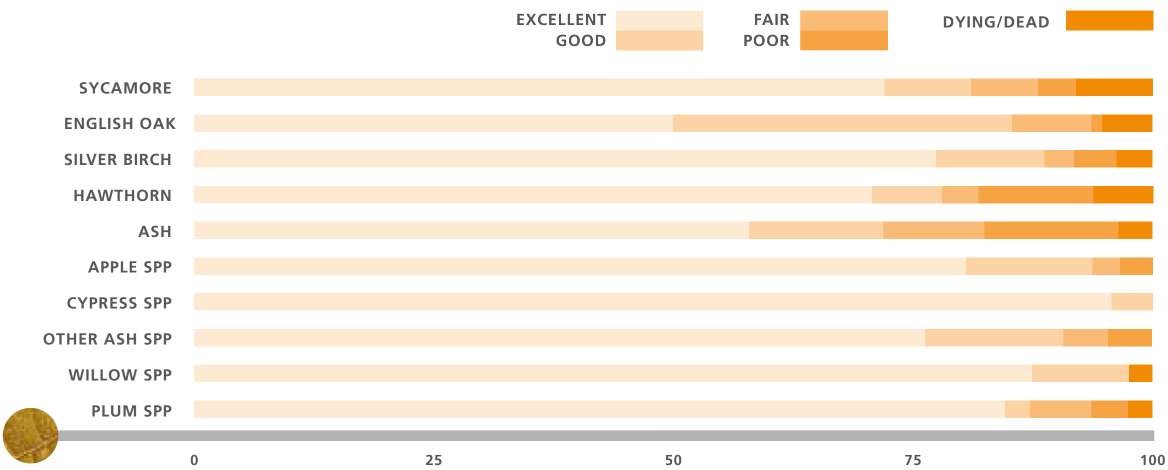

Fig 22. Condition of the 10 most common trees in London.

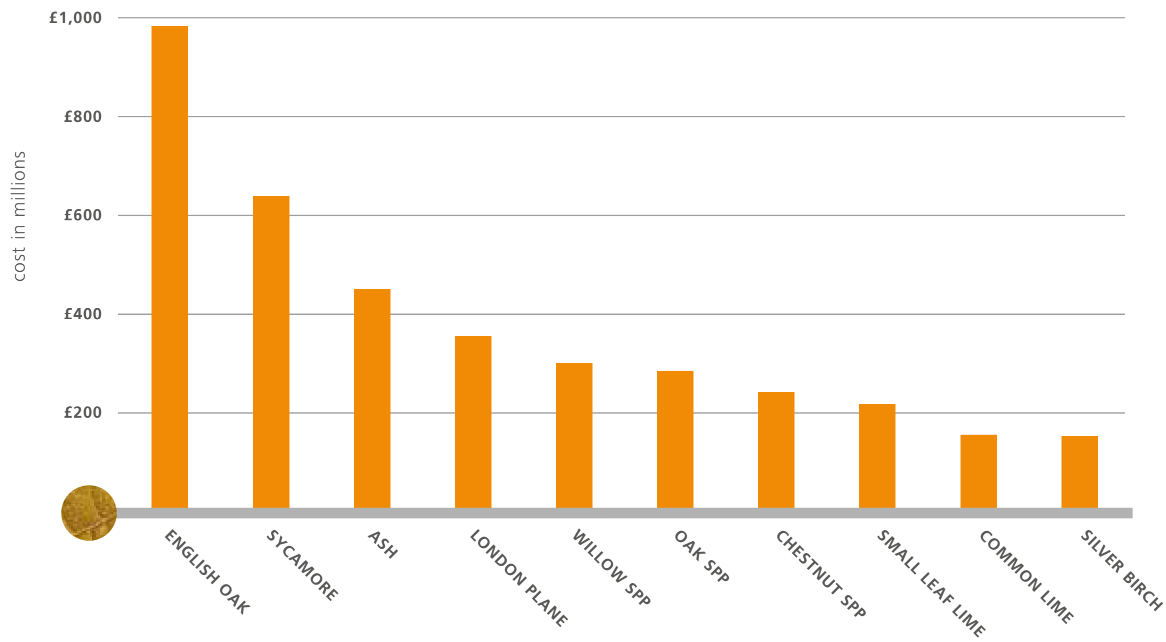

Fig 23. Replacement cost of the ten most valuable trees in London.

Replacement Cost

In addition to estimating the environmental benefits provided by trees the i-Tree Eco model also provides a structural valuation of the trees in the urban forest. 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[20]. The formula allows for tree suitability in the landscape and nursery prices.

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 fig 23 above.

The total replacement cost of all trees in London currently stands at £6.1 Billion Pounds.

Oak is the most valuable species of tree, on account of both its size and population, followed by sycamore and ash. These three species of tree account for £2.1 Billion (34%) of the total replacement cost of the trees in London.

A full list of trees with the associated replacement cost is given in appendix III.

20 This UK approved method is adapted for the UK by the Royal Institute of Chartered Surveyors (Hollis, 2007)

Conclusions

This project demonstrates just how much can be achieved when we engage with the largest stakeholders of our urban forest - the public. Without them this study (the world's largest urban forest survey using citizen science), this report, and what it reveals, would simply not have been possible.

In addition, London has also developed a core group of trained and skilled i-Tree surveyors from all walks of life. They are now able to carry out further i-Tree Eco (and other tree) surveys, thereby helping to raise awareness of the benefits of London's trees.

The data presented within this report represents a 'snapshot' in time of London's dynamic and ever-changing urban forest. It is an estimate of the current resource based on a survey of plots determined by a robust sampling methodology. Therefore, using this data to inform decisions on individual trees is not advised. However, this data can be used in a variety of ways to help inform decision making around the sustainable management of London's tree resource.

Furthermore, the values presented in this study represent only a fraction of the total value of London's urban forest because only a proportion of the total benefits have been evaluated. Trees contribute significantly towards many other environmental and social benefits, such as journey quality, biodiversity, temperature regulation and habitat that cannot yet be factored into i-Tree Eco. Therefore, the values presented in this report are conservative estimates of true value of the total benefits.

The report highlights that nearly 60% of trees in London are privately owned, and yet it is the publicly owned trees that contribute around 60% of the ecosystem services. This is due to the greater prevalence of mature and large canopy trees found in public ownership when compared to private ownership where the trees are often smaller varieties such as birch. Therefore everyone has a role to play in planting and managing trees, and that maintenance to ensure trees reach their full potential is paramount.

The structural resource results demonstrate high species diversity at pan London level - with differences between inner and outer London – but we should note that there is localised vulnerability. There are iconic treescapes that are made up of limited tree species and minimal genetic variation, with a range of issues threatening the health of those trees, so we need to ensure strategies are in place to protect them and make them more resilient.
The good age and structural variation found across London needs

to be actively managed. By protecting mature trees to retain their benefits, whilst planting new trees and maintaining existing trees will ensure London's tree resource will continue providing environmental and social benefits for future generations. Again, whilst tree cover across London is generally good, there are parts of London (often areas of social deprivation) that lack trees and hence do not receive the full benefits that this report highlights. Many woodlands have had little active management in recent years; restoring traditional practices would increase age and structural diversity that increase their resilience and deliver more benefits.

Leaf area plays a key part in determining the delivery of many ecosystem service benefits and thus trees that maximise their potential in a particular space may be favoured. Similarly, the report highlights that there are a wider range of benefits not included and the role of smaller and shorter lived trees in certain locations is also important.

Air quality is a particular issue across London and whilst the best solution is reduction of emissions, this report shows the crucial role that trees play in capturing pollutants and particulates from the air. Street trees can significantly improve air quality which will in turn provide health benefits if planned, planted and maintained carefully. Further work is needed to assess the precise benefits of trees on energy use, but we already know that the wider cooling effect of greenspace provided by trees benefits the surrounding area and can play a key role on public health during heatwaves by lowering peak summer temperatures.

This report has shown that threats to tree health would results in a reduction in ecosystem service provision. Climate change could affect the tree stock in a variety of ways and there are great uncertainties about how this may manifest. However, we do know that increased structural and species diversity is one way to mitigate for potential pest and climate effects. More tree planting of a wider species range, of varied origins and large canopy potential, will reduce future risk caused by pests and climate change. Further research into this area would be useful in informing any long term tree and woodland strategies, such as species choice for example.

The importance of a healthy, and diverse treescape needs to be more widely recognised, and strategies and policies that will serve to conserve this important resource (through stakeholder education for example) would be one way to address this.

There is potential for the tree stock to develop in the future, and provide greater benefits. As the amount of healthy leaf area equates directly to the provision of benefits, future management of the tree stock is important to ensure canopy cover levels continue to increase. This may be achieved via new planting, but the most effective strategy for increasing average tree size and the extent of tree canopy is to preserve and adopt a management approach that enables the existing trees to develop a stable, healthy, age and species diverse, multilayered population.

The challenge now is to ensure that policy makers and practitioners take full account of trees and woodlands in decision making. Not only are trees a valuable functional component of our landscape - they also make a significant contribution to people's health and quality of life. By securing a resilient tree population in London we are helping the city itself become more resilient.

Way Forward

The results presented in this report help to demonstrate both the range and scale of benefits provided by London's urban forest. How this information is used will be crucial in securing these benefits for decades to come.

We encourage everyone to use and share these results, so that this information on the benefits and economic value of urban trees is disseminated as widely as possible. Opportunities to use the data to engage the public – such as in demonstrating the positive relationship between trees and public health – are particularly welcomed.

The findings from this report will inform the forthcoming London Environment Strategy and the next iteration of the London Plan, both of which are being prepared by the Greater London Authority during 2016-2017.

Additionally, we hope this report inspires others to undertake i-Tree Eco surveys at the local level, from borough's down to neighbourhoods or even on individual trees. The upcoming updated version of i-Tree Eco will be fully automated for the UK, making it easier for individuals, communities and institutions to survey their trees and find out just how important they are.

Most importantly, we hope the findings from this report directly inform how London's tree population is managed. Everyone can play a part in enhancing London's tree cover, whether at home, at work or out in the streets and parks. Up to now, there was little common basis to ensure local initiatives could be shaped and targeted efficiently to maximise impacts - we worked on component parts without a clear picture of the greater whole.

With this report, for the first time, Londoners have a comprehensive understanding of the state of the urban forest, offering the opportunity to draw up a coherent range of concerted actions for enhanced tree care and continued tree planting.

In time it will be sensible to review the state of London's urban forest, comparing it against the benchmark evidence provided in this report to find out just how well we are doing. Making sure we maintain an urban forest that continues to provide benefits for ourselves and future generations will be a key indicator of London's performance as a sustainable, liveable city.

Please contact any of the project partners for further advice on potential next steps, and which organisations might be able to help. Also, please keep in mind: this report only offers a summary of the wealth of data generated from the i-Tree Eco survey.

The full results including the raw data are publicly available for download on the www.iTree.london.


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Appendices

Appendix I. Comparison with other Urban Forests

How does London compare to other cities? It is a question many will have. Comparison with cities at the global scale is interesting but should be made with caution, as there are many attributes of a city which will effect urban forest structure and function. Summary data are provided here from other cities analysed using the UFORE i-Tree Eco model.

City	Country	Number of trees	Tree cover (%)	Carbon storage (tonnes)	Carbon sequestration (tonnes / year)	Pollution removal (tonnes / year)
Toronto	Canada	10,200,000	20.0	1,100,100	46,700	1,430
London	UK	8,421,000	14.0	2,367,000	77,200	2,241
New York	US	5,212,000	20.9	1,350,000	42,300	1,677
Chicago	US	3,585,000	17.2	649,544	22,861	806
Glasgow	UK	2,000,000	15.0	183,000	9,000	283
Oakville	Canada	1,900,000	29.1	22,000	6,000	172
Barcelona	Spain	1,419,823	25.2	113,437	5,422	305
Torbay	UK	818,000	11.8	98,100	3,310	50
San Francisco	US	668,000	11.9	194,000	5,100	141
Morgantown	US	658,000	35.5	93,000	2,890	72
Edinburgh	UK	600,000	17.0	145,611	4,721	100
Moorestown	US	583,000	28.0	117,000	3,760	118
Providence	US	415,000	23.9	112,491	3,656	83
Wrexham	UK	364,000	17.0	66,000	1,300	60
Las Cruces	US	257,000	3.7	16,148	1,433	83
Udine	Italy	162,000	10.0	19,100	888	80
Jersey City	US	136,000	11.5	21,000	890	41
Casper	US	123,000	8.9	33,566	1,089	45
Freehold	US	48,000	34.4	20,000	545	22

London's urban forest compared to other British cities.

Appendix II. Species Importance Ranking

Rank	Genus	Species	Common Name	% Population	%Leaf Area	Dominance
1	Acer	pseudoplatanus	Sycamore	7.79	11.23	19.02
2	Quercus	robur	English oak	7.29	9.96	17.25
3	Betula	pendula	Silver birch	6.19	4.36	10.56
4	Fraxinus	excelsior	Ash	4.44	5.71	10.15
5	Crategus	monogyna	Hawthorn	6.17	2.48	8.66
6	Quercus	spp	Oak spp	2.72	3.94	6.66
7	Cupressus	spp	Cypress spp	3.62	3.04	6.66
8	Salix	spp	Willow spp	3.10	3.37	6.47
9	Fraxinus	spp	Ash spp	3.37	3.09	6.46
10	Acer	platanoides	Norway maple	2.36	3.46	5.81
11	Malus	spp	Apple spp	3.99	1.24	5.23
12	Platanus	x hispanica	London plane	1.36	3.84	5.20
13	Prunus	avium	Cherry	2.98	2.19	5.17
14	Prunus	spp	Plum spp	3.04	1.89	4.93
15	Tilia	cordata	Small Leaf Lime	1.32	3.12	4.45
16	Castanea	spp	Chestnut spp	1.93	2.30	4.23
17	Tilia	x europaea	Common lime	1.63	2.13	3.76
18	Cupressocyparis	leylandii	Leyland cypress	1.79	1.18	2.97
19	Betula	spp	Birch spp	2.29	0.66	2.95
20	Taxus	baccata	English yew	0.92	2.00	2.92
21	Aesculus	hippocastunum	Horsechestnut	0.93	1.95	2.88
22	Fagus	spp	Beech spp	0.21	2.61	2.82
23	Carpinus	betulus	Hornbeam	1.46	1.14	2.60
24	Ilex	aquifolium	Holly	1.65	0.62	2.27
25	Acer	campestre	Field maple	1.21	0.94	2.14
26	Pinus	spp	Pine spp	0.82	0.94	1.76
27	Chamaecyparis	spp	False cypress spp	1.11	0.63	1.74
28	Juglans	regia	Walnut	0.39	1.25	1.64
29	Tilia	americana	Basswood	0.54	1.01	1.55
30	Fagus	sylvatica	Beech	0.62	0.92	1.54
31	Picea	abies	Norway spruce	0.62	0.74	1.36
32	Ulmus	spp	Elm spp	1.11	0.21	1.32
33	Sambucus	nigra	Elder	0.94	0.28	1.22
34	Acer	saccharinum	Silver maple	0.35	0.82	1.17
35	Alnus	spp	Alder spp	0.47	0.65	1.12
36	Populus	x canescens	Grey poplar	0.78	0.26	1.04

Rank	Genus	Species	Common Name	% Population	%Leaf Area	Dominance
37	Taxus	baccata (f)	Irish Yew	0.68	0.35	1.03
38	Sorbus	aucuparia	Mountain ash	0.76	0.26	1.02
39	Alnus	cordata	Italian alder	0.39	0.58	0.97
40	Prunus	spinosa	Blackthorn	0.78	0.19	0.97
41	Quercus	petrea	Sessile oak	0.12	0.79	0.91
42	Salix	alba	White willow	0.37	0.54	0.91
43	Thuja	plicata	Western redcedar	0.27	0.60	0.87
44	Ostrya	carpinifolia	Hop-hornbean	0.47	0.40	0.87
45	Quercus	cerris	Turkey oak	0.70	0.16	0.86
46	Pyrus	spp	Pear spp	0.53	0.33	0.86
47	Pinus	sylvestris	Scots pine	0.39	0.41	0.80
48	Populus	nigra	Black poplar	0.27	0.53	0.80
49	Tilia	x euchlora	Crimean lime	0.08	0.68	0.76
50	Corylus	avellana	Hazel	0.47	0.28	0.75
51	Sorbus	americana	American Mountain ash	0.49	0.20	0.68
52	Ilex	Aquafolium	Holly	0.47	0.20	0.67
53	Carpinus	spp	Hornbeam spp	0.16	0.51	0.66
54	Magnolia	spp	Magnolia spp	0.45	0.19	0.64
55	Prunus	sargentii	Sargent cherry	0.41	0.23	0.64
56	Prunus	americana	Purpleleaf plum	0.29	0.35	0.64
57	Prunus	domestica	Common plum	0.51	0.13	0.63
58	Robinia	pseudoacacia	False Acacia	0.31	0.30	0.61
59	Prunus	cerasifera	Cherry plum	0.47	0.15	0.61
60	Griseliana	littoralis	Kapuka	0.52	0.09	0.61
61	Fagus	spp	Beech spp	0.17	0.43	0.61
62	Ficus	spp	Fig spp	0.37	0.21	0.58
63	Populus	spp	Poplar spp	0.08	0.48	0.56
64	Prunus	laurocerasus	Cherry laurel	0.47	0.09	0.55
65	Larus	noblis	Bay tree	0.27	0.25	0.52
66	Fraxinus	augustifolia	Narrow-leafed ash	0.16	0.36	0.51
67	Populus	alba	White poplar	0.21	0.27	0.48
68	Betula	utilis	Indian paper birch	0.29	0.12	0.41
69	Malus	pumila	Common apple	0.17	0.20	0.38
70	Prunus	serrulata	Kwanzan cherry	0.31	0.06	0.38
71	Quercus	ilex	Holm Oak	0.17	0.18	0.35
72	Gleditsia	spp	Locust spp	0.16	0.17	0.32
73	Trachycarpus	fortunei	Windmill palm spp	0.23	0.07	0.30
74	Larix	decidua	European larch	0.06	0.23	0.29
75	Liriodendron	tulipifera	Tulip tree	0.16	0.12	0.27
76	Catalpa	bignonioides	Southern catalpa	0.12	0.15	0.27
77	Alunus	glutinosa	European alder	0.16	0.10	0.26
78	Pyrus	communis	Common pear	0.21	0.03	0.24
79	Liquidambar	styraciflua	Sweetgum spp	0.06	0.16	0.22
80	Salix	babylonica	Weeping willow	0.08	0.14	0.22
81	Prunus	subhirtella	Higan cherry	0.17	0.04	0.21
82	Tilia	spp	Lime spp	0.08	0.13	0.21
83	Platanus	occidentalis	Occidental plane	0.08	0.13	0.21
84	Olea	spp	Olive spp	0.16	0.05	0.21
85	Cotoneaster	spp	Cotoneaster spp	0.14	0.06	0.20
86	Lauristinus	spp	Laurustinus	0.16	0.04	0.20
87	Prunus	cerasifera 'Atropurpurea'	Ciruelo rojo	0.06	0.14	0.20

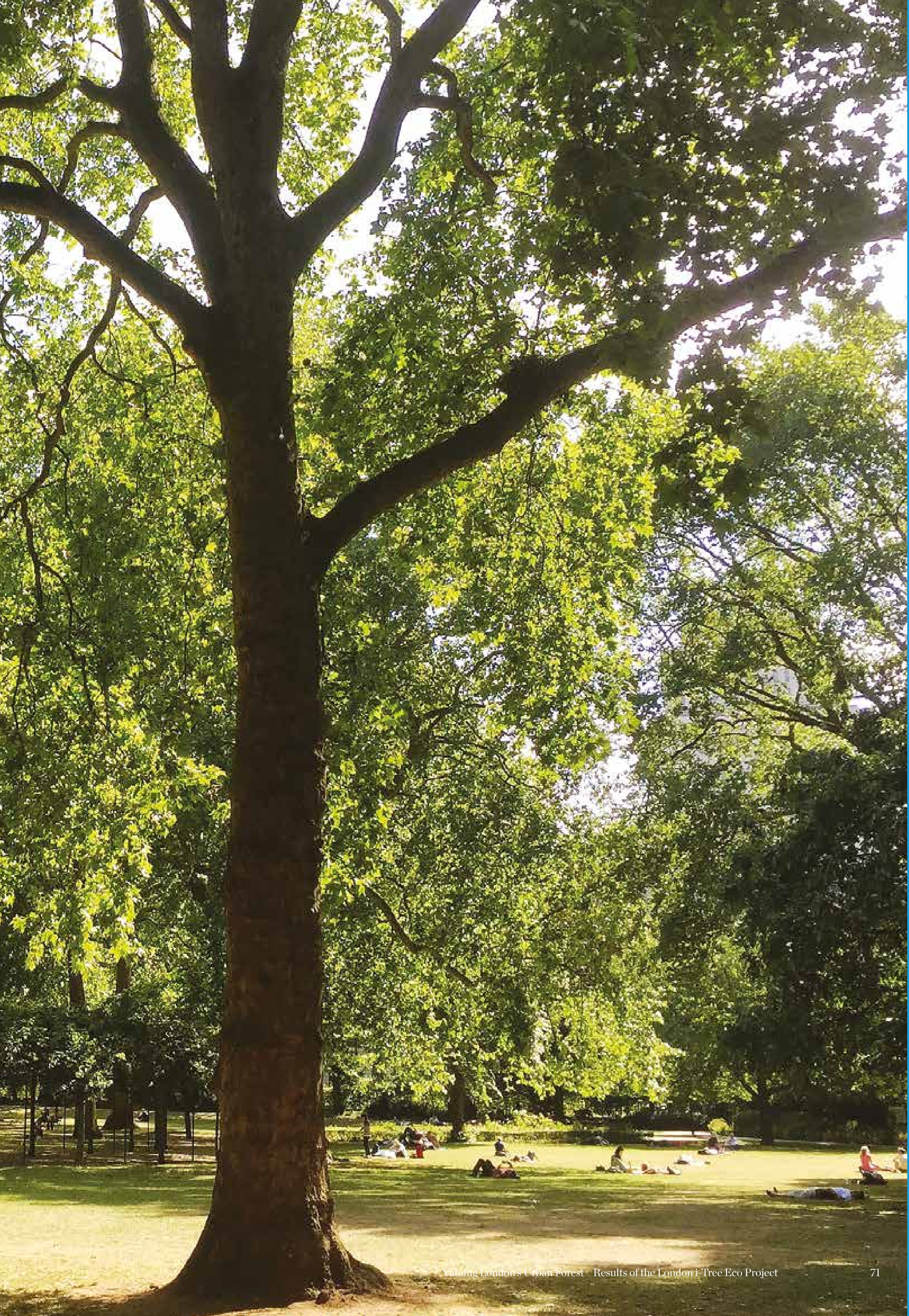
Rank	Genus	Species	Common Name	% Population	%Leaf Area	Dominance
88	Crategus	crusgalli	Cockspur hawthorn	0.16	0.04	0.20
89	Prunus	padus	Bird cherry	0.16	0.03	0.19
90	Acer	cappadocian	Cappadocian maple	0.06	0.13	0.18
91	Rhododendron	spp	Rhododendron spp	0.17	0.01	0.18
92	Juniperus	spp	Juniper spp	0.16	0.02	0.18
93	Laburnam	spp	Golden chain tree spp	0.14	0.04	0.17
94	Larix	kaempferi	Japanese larch	0.08	0.07	0.14
95	Amelanchier	arborea	Downy serviceberry	0.14	0.01	0.14
96	Ulmus	minor	English elm	0.14	0.00	0.14
97	Acacia	spp	Acacia spp	0.08	0.05	0.13
98	Washingtonia	robusta	Mexican fan palm	0.08	0.04	0.12
99	Chamaecyparis	lawsonia	Lawson Cypress	0.08	0.04	0.11
100	Rhamnus	cathartica	Buckthorn	0.08	0.03	0.11
101	Ulmus	spp	Elm	0.06	0.05	0.11
102	Picea	spp	Spruce spp	0.08	0.03	0.11
103	Tamarix	spp	Tamarisk	0.08	0.03	0.11
104	Litchi	chinesis	Lychee	0.08	0.03	0.11
105	Corylus	colurna	Turkish hazel	0.08	0.03	0.11
106	Eucalyptus	spp	Gum spp	0.06	0.04	0.10
107	Viburnum	rhytidophyllum	Leather leaf viburnum	0.06	0.04	0.10
108	Laurus	noblis	Bay Laurel	0.06	0.04	0.09
109	Cercis	siliquastrum	Judas Tree	0.08	0.01	0.09
110	Pinus	nigra	Corsican pine	0.06	0.03	0.09
111	Amelanchier	canadensis	Eastern service berry	0.08	0.01	0.09
112	Clerodendron	trichotonum	Glorybower spp	0.08	0.01	0.09
113	Crategus	laevigata	Scarlet hawthorn	0.08	0.01	0.09
114	Salix	caprea	Goat willow	0.06	0.03	0.09
115	Ceanothus	spp	Ceanothus spp	0.08	0.01	0.09
116	Prunus	lusitanica	Portugal laurel	0.08	0.01	0.09
117	Cordyline	australis	Giant dracaena	0.08	0.01	0.08
118	Phoenix	dactylifera	Date palm spp	0.08	0.01	0.08
119	Betula	nigra	Northern birch	0.06	0.02	0.08
120	Amelanchier	spp	Serviceberry spp	0.08	0.00	0.08
121	Sequoia	spp	Redwood spp	0.08	0.00	0.08
122	Acer	palmatum	Japanese maple	0.08	0.00	0.08
123	Cupressus	macrocarpa	Golden montery cypress	0.08	0.00	0.08
124	Betula	papyrifera	Paper birch	0.06	0.01	0.07
125	Cercis	spp	Redbud spp	0.06	0.01	0.06
126	Lawsonia	spp	Lawsonia spp	0.06	0.01	0.06
127	Cupressus	sempervirens	Italian cypress	0.06	0.00	0.06

Appendix III.
Full Species List

Species	Number of Trees	Carbon (ϖmt)	Gross Seq (ϖmt/yr)	Net Seq (ϖmt/yr)	Leaf Area (km²)	Leaf Biomass (ϖmt)	Replacement Cost
English oak	613,562	481,795	11,401	10,012	104.314	6,945	£981,243,502
Sycamore	656,085	216,414	7,579	6,603	117.607	8,224	£638,225,621
Ash	374,195	163,217	3,817	2,896	59.763	6,358	£447,345,251
London plane	114,537	143,050	3,386	3,167	40.224	1,756	£351,623,660
Willow spp	260,927	136,170	2,131	1,751	35.28	2,178	£297,301,384
Oak spp	229,471	149,318	3,076	2,644	41.252	4,071	£281,480,595
Chestnut spp	162,454	98,710	2,113	1,910	24.09	1,689	£238,217,193
Small leaf Lime	111,403	39,744	1290	1,126	32.726	2,451	£213,662,425
Common lime	137,365	33,176	1,174	890	22.328	1,039	£151,020,672
Silver birch	521,556	64,163	3,972	3,731	45.692	2,714	£149,285,937
Beech spp	18,028	45,228	274	104	27.292	1,366	£133,382,782
Norway maple	198,412	41,279	1,750	1,633	36.198	1,954	£128,359,402
Ash spp	283,755	46,183	2,119	1,984	32.334	2,913	£120,097,452
Cypress spp	305,215	25,665	1,474	1,375	31.809	4,981	£110,998,649
Black poplar	22,927	34,606	770	673	5.502	397	£110,737,086
Horse chestnut	78,679	67,049	1,472	-1,403	20.398	1,426	£99,658,461
English yew	77,112	16,251	529	475	20.981	3,286	£91,831,518
Hawthorn	519,989	42,329	2,398	2,158	26.016	3,273	£88,030,561
Plum spp	255,730	38,330	2,352	2,155	19.816	1,533	£76,815,164
Sweet cherry	251,030	30,029	2,082	1,974	22.977	1,778	£75,748,268
Pine spp	68,881	15,705	446	372	9.818	946	£71,671,131
Poplar spp	6,565	33,027	412	339	5.053	341	£68,995,287
Sessile oak	9,798	32,509	369	270	8.312	820	£61,787,483
Apple spp	335,975	19,761	1,952	1,841	12.955	1,117	£61,361,389
European hornbeam	122,867	23,656	883	742	11.986	722	£59,410,222
Silver maple	29,492	11,443	306	276	8.544	450	£58,588,934
Leyland cypress	150,991	13,470	597	434	12.311	1,928	£49,836,711
Basswood spp	45,854	10,731	467	435	10.553	491	£49,270,469
Hornbeam spp	13,130	13,303	403	353	5.316	320	£36,745,777
Indian Bean tree	9,798	17,177	287	248	1.612	86	£35,758,037
Alder spp	39,389	13,270	506	486	6.845	378	£35,034,895
English walnut	32,824	10,576	537	483	13.123	553	£34,248,960
Turkey oak	59,083	11,735	571	544	1.653	163	£33,110,156
Field maple	101,705	11,087	695	648	9.799	551	£30,011,431

Species	Number of Trees	Carbon (ϖmt)	Gross Seq (ϖmt/yr)	Net Seq (ϖmt/yr)	Leaf Area (km²)	Leaf Biomass (ϖmt)	Replacement Cost
False cypress spp	93,474	8,288	488	452	6.579	1,645	£29,671,917
Holly spp	139,229	9,335	905	864	6.505	870	£26,219,825
Western redcedar	22,927	2,672	66	56	6.267	1,205	£24,736,634
Hop-hornbean	39,389	10,906	417	409	4.176	273	£24,550,497
Narrow-leafed ash	13,130	6,435	233	214	3.731	266	£23,965,916
Mountain ash spp	63,883	7,961	513	470	2.702	214	£23,548,328
White poplar	18,028	5,559	197	184	2.818	245	£22,080,745
Gray poplar	65,648	7,647	349	343	2.718	196	£21,209,816
Crimean linden	6,565	3,345	114	101	7.142	332	£20,748,662
Beech spp	14,696	5,676	278	256	4.55	228	£18,928,891
Italian alder	32,725	5,334	312	292	6.11	445	£17,404,026
Beech	52,519	9,078	519	501	9.611	481	£17,058,292
European alder	13,130	6,703	223	197	1.055	77	£17,014,366
Birch spp	192,719	2,290	598	576	6.941	434	£15,835,337
Norway spruce	52,519	5,811	324	304	7.723	1,287	£15,747,570
Tulip tree	13,130	4,247	198	181	1.243	73	£15,418,069
Common apple	14,696	5,091	180	143	2.132	184	£13,351,989
Purpleleaf plum	24,593	5,357	326	315	3.617	280	£12,144,753
Scots pine	32,824	3,543	141	139	4.302	415	£11,969,923
Yew spp	57,318	2,132	139	134	3.63	568	£11,363,349
White willow	31,158	5,185	265	260	5.645	358	£11,253,919
Locust spp	13,130	3,751	154	146	1.76	184	£11,156,940
Windmill palm spp	19,694	82	2	2	0.698	117	£10,331,582
Sargent cherry	34,391	3,740	234	203	2.42	187	£9,984,108
Holly oak	14,696	3,382	142	133	1.874	185	£9,894,928
American Mountain ash	40,956	2,961	279	268	2.059	163	£9,801,401
False acacia	26,160	4,736	241	221	3.167	170	£9,774,740
Bay tree spp	22,927	3,049	218	206	2.567	192	£9,702,996
Occidental plane	6,565	3,350	141	138	1.389	64	£9,321,140
Mexican fan palm	6,565	77	1	1	0.425	66	£9,100,548
Pear spp	44,288	3,839	320	206	3.492	261	£8,726,385
Kwanzan cherry	26,259	4,309	262	257	0.677	52	£8,712,381
Fig spp	31,158	3,076	253	240	2.173	163	£8,692,131
Weeping willow	6,565	2,523	119	109	1.476	94	£8,594,719
Common plum	42,622	3,955	333	317	1.334	103	£8,431,499
Leather leaf viburnum	4,899	2324	77	72	0.401	30	£7,942,299
Ciruelo rojo	4,899	3,320	134	121	1.455	113	£7,912,230
Date palm spp	6,565	26	1	1	0.065	11	£7,764,323
Elder	78,778	5,010	271	-91	2.933	220	£7,027,840
Magnolia spp	37,723	2,298	254	244	2.04	136	£6,369,845
Cherry laurel	39,389	2,493	298	287	0.896	69	£6,157,528
Hazel	39,389	2,126	207	201	2.926	203	£5,824,696
Higan cherry	14,696	2,521	187	185	0.396	31	£5,084,307
Cherry plum	39,389	2,426	276	271	1.519	92	£4,773,851
Bird cherry	13,130	1,908	135	133	0.344	27	£4,716,574
Kapuka	44,089	2,355	173	159	0.931	70	£4,345,869
Sweetgum spp	4,899	487	18	16	1.718	79	£3,949,922
Portugal laurel	6,565	1,418	104	99	0.075	6	£3,943,463

Species	Number of Trees	Carbon (ϖmt)	Gross Seq (ϖmt/yr)	Net Seq (ϖmt/yr)	Leaf Area (km²)	Leaf Biomass (ϖmt)	Replacement Cost
Giant dracaena	6,565	12	0	0	0.073	12	£3,755,647
Dutch elm	4,899	2,011	66	61	0.545	37	£3,142,196
Lawson cypress	6,565	566	36	34	0.385	96	£2,957,151
Blackthorn	65,648	2,516	173	137	2.012	156	£2,816,975
Elm spp	93,474	3,003	205	91	2.225	152	£2,551,383
Corsican pine	4,899	362	25	23	0.348	34	£2,427,163
Cockspur hawthorn	13,130	957	103	102	0.424	32	£2,298,322
Large leaf Lime	6,565	592	48	48	1.403	83	£2,164,619
Indian paper birch	24,593	879	151	148	1.274	76	£2,003,759
English holly	39,389	937	98	97	2.144	287	£1,974,492
Turkish hazel	6,565	760	67	66	0.311	22	£1,921,414
European larch	4,899	399	19	18	2.441	132	£1,652,751
Japanese larch	6,565	936	37	37	0.698	45	£1,624,427
Cappadocian maple	4,899	560	32	31	1.311	74	£1,502,789
Gum spp	4,899	574	49	47	0.439	57	£1,302,315
Lychee	6,565	526	53	51	0.318	24	£1,301,766
Acacia spp	6,565	496	34	32	0.495	120	£1,262,461
Common pear	18,028	557	70	39	0.307	23	£1,160,961
Juniper spp	13,130	318	37	35	0.203	56	£991,538
Olive spp	13,130	305	57	55	0.545	41	£935,364
Rhododendron spp	14,696	295	32	30	0.088	18	£930,481
Spruce spp	6,565	461	28	28	0.331	56	£899,850
Downy serviceberry	11,464	181	34	33	0.063	4	£869,562
Golden chain tree spp	11,464	552	74	70	0.379	28	£804,873
Paper birch	4,899	393	46	45	0.084	6	£753,656
Bay laurel	4,899	323	24	23	0.368	28	£727,278
Lawsonia spp	4,899	344	37	36	0.053	4	£631,509
Cotoneaster spp	11,464	227	46	45	0.664	50	£604,753
Laurustinus	13,130	335	35	-1	0.432	32	£504,984
Tamarisk spp	6,565	217	37	36	0.318	24	£501,087
Japanese maple	6,565	41	12	12	0.04	2	£492,362
Serviceberry spp	6,565	56	17	17	0.05	4	£492,362
Eastern service berry	6,565	84	22	21	0.129	10	£492,362
Northern birch	4,899	135	16	16	0.261	16	£459,261
Judas tree	6,565	129	28	27	0.146	9	£434,277
Buckthorn	6,565	94	22	21	0.353	26	£434,277
Glorybower spp	6,565	103	24	24	0.124	9	£361,898
Scarlet hawthorn	6,565	85	22	22	0.123	9	£361,898
Ceanothus spp	6,565	108	25	23	0.112	8	£356,107
Goat willow	4,899	82	11	11	0.329	21	£349,038
Redwood spp	6,565	345	9	6	0.047	7	£338,689
Golden montery cypress	6,565	22	6	6	0.025	4	£308,711
Redbud spp	4,899	44	13	13	0.07	4	£307,862
Italian cypress	4, 899	57	11	11	0.03	5	£303,112



Appendix IV. Notes on Methodology

i-Tree Eco is designed to use standardised field data from randomly located plots 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, sulfur dioxide, nitrogen dioxide, carbon monoxide and particulate matter (<2.5 microns and <10 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 (but not limited too) Asian longhorned beetle, emerald ash borer, gypsy moth, and Dutch elm disease.

In the field 0.04 hectare plots were randomly distributed. All field data were collected during the leaf-on season to properly assess tree canopies. Within each plot, data collection includes land use, ground and tree cover, individual tree attributes of species, stem diameter, height, crown width, crown canopy missing and dieback.

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[21]. 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.

21 Nowak, 1994

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 O2 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[22].

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, and sulfur and nitrogen dioxides based on a hybrid of big-leaf and multi-layer canopy deposition models[23]. 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[24,25] that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere[26].

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. As the local values include the cost of treating the water as part of a combined sewage system the lower, national average externality value for the United States is utilised and converted to local currency with user-defined exchange rates.

Replacement Costs were based on valuation procedures of the Council of Tree and Landscape Appraisers, which uses tree species, diameter, condition and location information[27,28].

22 Nowak, Hoehn and Crane, 2007
23 Baldocchi, Hicks and Camara, 1987 and Baldocchi, 1988
24 Bidwell and Fraser, 1972
25 Lovett, 1994
26 Zinke, 1967
27 Hollis, 2007
28 Rogers et al., 2012

US externality and UK social damage costs

The i-Tree Eco model provides figures using US externality and abatement costs. Basically speaking this reflects the cost of what it would take a technology (or machine) to carry out the same function that the trees are performing, such as scrubbing the air or locking up carbon.

For the UK however, the appropriate way to monetise the carbon sequestration benefit is to multiply the tonnes of carbon stored by the non-traded price of carbon, because this carbon is not part of the EU carbon trading scheme. The non-traded price is not based on the cost to society of emitting the carbon, but is based on the cost of not emitting the tonne of carbon elsewhere in the UK in order to remain compliant with the Climate Change Act[29].

This approach gives higher values to carbon than the approach used in the United States, reflecting the UK Government's response to the latest science, which shows that deep cuts in emissions are required to avoid the worst affects of climate change.

Official pollution values for the UK are based on the estimated social cost of the pollutant in terms of impact upon human health, damage to buildings and crops. Values were taken from the Interdepartmental Group on Costs and Benefits (IGCB) based on work by DE-FRA[30]. They are a conservative estimate because they do not include damage to ecosystems; SO_2 negatively impacts trees and freshwater and NO_x contributes to acidification and eutrophication. For PM_{10s}, which are the largest element of the air pollution benefit, a range of economic values is available depending on how urban (hence densely populated) the area under consideration is. We used the 'transport outer conurbation' values as a conservative best fit, given the population density data above.

For both carbon and air pollution removal, the assumption has been made that the benefit to society from a tonne of gas removed is the same as the cost of a tonne of the same gas emitted.

For a full review of the model see UFORE (2010) and Nowak et al (2010).

For UK implementation see Rogers et al. (2012).
Full citation details are located in the bibliography section.

29 DECC, 2011
30 DEFRA, 2007

CAVAT
The Amenity Value of London's Trees

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).

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, to add another dimension to the utilitarian approach which is adopted in the CTLA method[31]. Both methods offer a valid analysis.

CAVAT allows the value of London's trees to include a social dimension by valuing the visual accessibility and prominence within the overall urban forest.

Particular differences to the CTLA method includes the addition and consideration of the Community Tree Index (CTI), which adjusts the CAVAT assessment to take account of the greater amenity benefits of trees in areas of higher population density, using official population figures. For the full method see appendix IV

According to the CAVAT valuation, London's urban forest is estimated to be worth an estimated £43.3 billion.

As an asset to Greater London, the above figure is equivalent to over 25 times the cost of constructing Wembley Stadium.

The Oak's of London hold the highest CAVAT value (Table 12), representing nearly 8% of the total of all the trees.

31 For full details on the CAVAT system see: www.ltoa.org.uk/resources/cavat. For details of CTLA see Hollis (2007).

The single most valuable tree encountered in the study was also an Oak, situated in Outer plot 126, estimated have an amenity value of £189,672.00.

Parks hold most of the amenity value of trees, with the total value of trees within this land use type estimated at approximately £3.1 million in the plots sampled. This is 20% of the amenity value held by London's trees (fig 26) illustrating the importance of London's parks to its inhabitants. Residential areas are also important as they hold 36% of the amenity value totalling £1.5 million pounds.

Comparing the CAVAT value of the top 10 species for Inner and Outer (see fig 25 page 78) London highlights the dominance of the London plane (*Platanus hispanica*) in the inner areas, with this species accounting for 29% of the amenity value. In the outer areas oak (*Quercus robur*) holds the majority of amenity value. All of the tree species represented are larger stature species, with the exception of Silver Birch (*Betula pendula*). The amenity value of trees to be found on residential land is also highlighted with almost a third of the total amenity value to be found on this land use.

Land Use	Street Tree	Accessibility %
Land Use	Street Tree	Accessibility %
Agriculture	S	100
Agriculture	N	40
Cemetery	S	100
Cemetery	N	80
Comm/Ind	S	100
Comm/Ind	N	40
Golf Course	S	100
Golf Course	N	60
Institutional	S	100
Institutional	N	80
Multi Family Residential	S	100
Multi Family Residential	N	80
Other	S	100
Other	N	60
Park	S	100
Park	N	100
Residential	S	100
Residential	N	60
Transportation	S	100
Transportation	N	40
Utility	S	100
Utility	N	20
Vacant	S	100
Vacant	N	80
Water/Wetland	S	100
Water/Wetland	N	60

Table 13. accessibility weightings for CAVAT.

Scientific Name	Percentage	Value by Species	Value across London
Quercus	9.45%	£1,291,561	£7,046,844,393
Acer	12.92%	£1,182,653	£6,452,634,541
Platanus	2.03%	£1,031,863	£5,629,912,604
Fraxinus	7.33%	£579,389	£3,161,184,564
Tilia	5.30%	£604,370	£3,297,482,682
Salix	2.89%	£398,866	£2,176,239,609
Prunus	10.80%	£396,244	£2,161,931,513
Populus	1.74%	£329,950	£1,800,232,333
Fagus	1.06%	£212,661	£1,160,293,381
Aesculus	1.16%	£210,458	£1,148,270,936
Cupressus	4.73%	£163,558	£892,382,050
Betula	4.53%	£171,089	£933,471,895
Castanea	1.35%	£102,092	£557,020,391
Crataegus	4.73%	£95,536	£521,253,202
Catalpa	0.19%	£112,979	£616,423,683
Malus	5.01%	£87,987	£480,061,066
Sorbus	1.74%	£111,486	£608,274,556
Carpinus	1.83%	£72,793	£397,165,712
Taxus	1.54%	£73,160	£399,168,250
Sub-Total	**80.33%**	**£7,228,694**	**£39,440,247,360**
Other Species	19.67%	£712,266	£3,886,171,702
Total	**100.00%**	**£7,940,960**	**£43,326,419,063**

Fig 24. % CAVAT by Genus top 20.

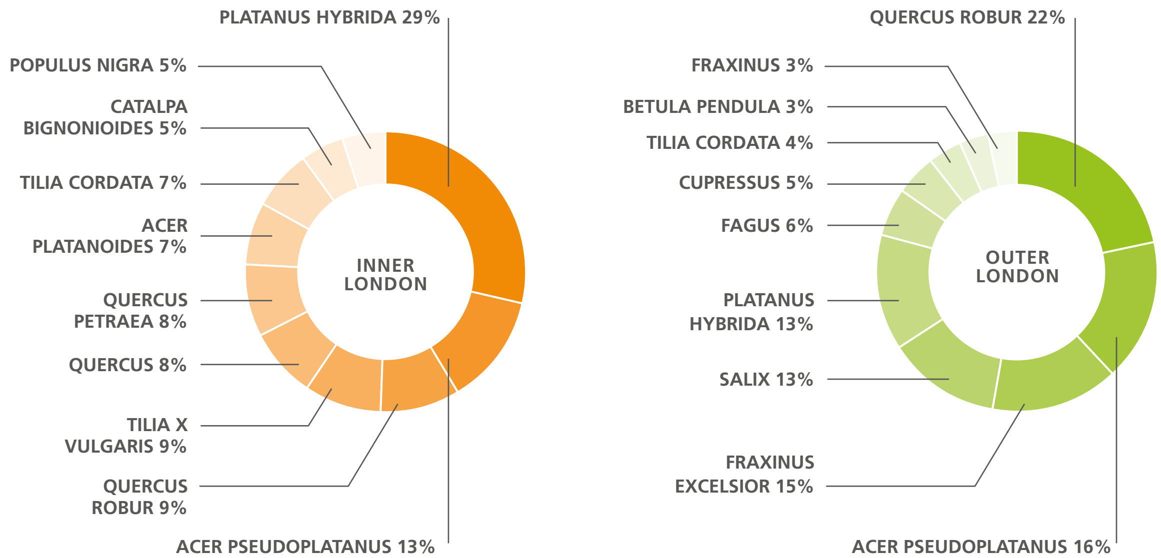


Fig 25. Above shows the % CAVAT value by tree species for Inner London and below for Outer London.

Fig 26. Percentage of amenity value held by trees on different land use types according to CAVAT analysis. Land use types where no trees were found are omitted.

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