i-Tree Eco Inventory Report
Public Trees

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Camden

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Executive Summary

Camden's trees are generally recognised and appreciated by their presence and stature in the townscape, but society is often unaware of the many benefits that trees provide to those living in our towns and cities.

The trees in our towns and cities (together with woodlands, shrubs, hedges, open grass and wetland) are collectively known as the urban forest. This urban forest improves our air, protects watercourses, saves energy, and improves economic sustainability[1]. There are also many health and well being benefits associated with being in close proximity to trees and there is a growing research base to support this.[2]

Economic valuation of the benefits provided by our natural capital[3] can help to mitigate for development impacts, inform land use changes and reduce any potential impact through planned intervention to avoid a net loss of natural capital. Such information can be used to help make better management decisions. The benefits provided by such natural capital is often poorly understood. Consequently, these benefits (or ecosystem services) are often undervalued in the decision making process.

In order to produce values for some of the benefits provided by trees a state of the art, peer reviewed software system called i-Tree Eco[4] (referred to as 'Eco' throughout the report) was used.

Highlights Include:

The publicly owned trees in Camden remove over 5 tonnes of airborne pollutants each year and store 10,800 tonnes of Carbon.

Existing trees in Camden divert an estimated 6,700 cubic meters of storm water runoff away from the local sewer systems each year. This is worth £10,200 each year in avoided stormwater treatment costs.

The total replacement cost of all trees in Camden currently stands at £43.5 million
Table 1 (below) contains the headline figures.

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1 Doick et al (2016)

2 http://depts.washington.edu/hhwb/

3 Natural capital can be defined as the world's stocks of natural assets which include geology, soil, air, water, trees and all living things

4 i-Tree Eco is i-Tree is a suite of open source, peer-reviewed and continuously improved software tools developed by the USDA Forest Service and collaborators to help urban foresters and planners assess and manage urban tree populations and the benefits they can provide. i-Tree Eco is one of the tools in the i-Tree suite. It is designed to use complete or sample plot inventory(ies) from a study area along with other local environmental data to:
Characterise the structure of the tree population,
Quantify some of the environmental functions it performs in relation to air quality improvement, carbon dioxide reduction, and stormwater control,
Assess the value of the annual benefits derived from these functions as well as the estimated worth of each tree as it exists in the landscape.
I-Tree Eco is adaptable to multiple scales from a single tree to area-wide assessments.
For more information see www.itreetools.org

Camden Public Tree Inventory - Headline Figures		
Total Number of Trees Measured	25,890	
Tree Canopy Cover	107 hectares	
Most Common Species	Platanus, Tilia x europaea, Acer pseudoplatanus	
Replacement Cost	£43,536,000.00	
Species Recorded	258	
Amounts and Values		
Pollution Removal	5 tonnes	£175,500.00
Carbon Storage	10,800 tonnes	£691,300.00
Carbon Sequestration (trees)	207 tonnes	£48,483.00
Avoided Runoff (trees)	6,739m³	£10,219.00
Total Annual Benefits	£234,202	

Table 1: Headline figures.

Total Number of Trees Measured: Not all records supplied were used in the analysis. Furthermore, some records contained entries for multiple trees, in order to process these combined entries they were separated into individual records for each tree. For further details see the methodology section below.
Tree Canopy Cover: The area of ground covered by leaves when viewed from above (not to be confused Leaf area which is the total surface area of leaves). This is not the total canopy cover for Camden as private trees were not included in the analysis and some tree canopy dimensions were conservatively estimated.
Replacement Cost: value based on the physical resource itself (e.g., the cost of having to replace a tree with a similar tree) using the Council of Tree and Landscape Appraisers Methodology guidance from the Royal Institute of Chartered Surveyors
Carbon storage: the amount of carbon bound up in the above-ground and below-ground parts of woody vegetation.
Carbon sequestration: the annual removal of carbon dioxide from the air by plants
Carbon storage and carbon sequestration values are calculated based on DECC figures of £64 per metric ton for 2017
Pollution removal: This value is calculated based on the UK social damage costs and the US externality prices where UK figures are not available; £0.984 per KG (carbon monoxide), £27.330 per KG (ozone), £4.082 per KG (nitrogen dioxide), £1.487 per KG (sulphur dioxide), £948.657 per KG (particulate matter less than 2.5 microns).
Avoided Runoff: Based on the amount of water held in the tree canopy and re-evaporated after the rainfall event. The value is based on an average volumetric charge of £1.516p per cubic metre and includes the cost of avoided energy and associated greenhouse gas emissions.

Data processed using iTree Eco Version 6.1.18.

Methodology

Camden Council's tree inventory, exported to xls (which included 25,144 records) was reformatted and the uploaded into Eco. Amongst the data collected were tree species, height, diameter at breast height (DBH), crown width and crown condition. Some of the supplied records contained multiple trees, however, Eco requires each tree to have its own record or line of data in the imported spreadsheet.

The minimum data required by Eco is tree species and the dbh. However, the more data that is available for each tree will result in a more accurate range of model calculations (height and crown spread for example). Trees without the minimum required data were removed from the records as they cannot be processed. Data for woodland blocks and tree groups were also provided but unfortunately due to formatting and missing data, these records could not be processed.

The Eco software also requires data to be inputted in a particular format with values over 0 for all the structural data of each tree. Several estimates had to be inputted based on the information available within the provided tree inventory. Tables 2-7 below show the list of edits and assumptions which were made for this project, to enable the maximum amount of trees to be processed.

Out of an original 25,144 records, 1,079 were removed due to insufficient data. However, 1,825 trees were added as multiples in avenues etc. In total 25,890 records were processed.

Reason for Addition	Details	Number of records added
Multiple quantity of Trees	Multiple trees were recorded in single row of data for avenues and hedges. These were duplicated for the quantity recorded in the provided inventory spreadsheet so that each tree had a separate record or line of data.	1,825

Table 2: Records Added to Spreadsheet

Reason for Edit	Details	Number of records changed
Blank Condition	For fields without a condition rating we have assumed a Fair Condition at 82%	96
Not Applicable Condition	For fields without a valid condition rating we have assumed a Fair Condition at 82%	771
Crown Width	iTree requires a crown width so for those trees with a missing crown width the figure has been estimated (see table below).	107
Height	iTree requires a height so for those trees with a missing height the figure has been estimated (see table below).	10
Crown Health	iTree requires a crown health rating so as a default a condition of 90% has been assumed for all trees.	All
Crown Base	iTree requires a crown base so the figure has been estimated (see table below).	All
Crown Missing	iTree requires a crown missing rating so as a default if 10% has been assumed missing for all trees.	All

Table 3: Records Removed from Spreadsheet

Reason for Removal	Details	Number of records removed
No DBH	There is no data in this field (a minimum requirement for iTree)	594
DBH < 2.5cm	The minimum DBH for iTree is 2.5cm	79
Condition = "Dead"	The tree has died	87
Ward = "Out of Borough"	The trees were not within the 'Camden' boundary	221
Invalid Species Name	The species name was not accepted by iTree Eco (e.g. Stump)	98
	NUMBER OF RECORDS IMPORTED	**25,890**

Table 4: Records Edited in Spreadsheet

DBH (cm)	Height (m)	Crown Base (m)	Crown Width N-S (m)	Crown Width E-W (m)
2-10	3	0.5	4	4
11-15	5	1	5	5
16–20	10	2	6	6
21+	15	3	8	8

Table 5: Height and Crown Estimates Based on DBH

Condition Text	iTree Equivalent
Excellent Condition	100%
Good Condition	92%
Fair Condition	82%
Poor Condition	62%

Table 6: iTree Condition Equivalents

Original Ward	New Ward	Number of Records Changed
Brunswick Ward	Bloomsbury Ward	3
Camden Ward	Camden Town with Primrose Hill	12
Caversham Ward	Kentish Town Ward	1
Fitzjohns Ward	Frognal and Fitzjohns Ward	39
Somers Town Ward	St Pancras and Somers Town	22
St Pancras	St Pancras and Somers Town	25

Table 7: Camden Ward Changes

The inventory data is processed within Eco using the in-built local pollution and climate data to provide the following results (listed in table 8 below).

Tree Structure and Composition	Species diversity. Dbh size classes. Leaf area. % leaf area by species.
Ecosystem Services	Air pollution removal by urban trees for CO, NO_2, SO_2, O_3 and $PM_{2.5}$ % of total air pollution removed by trees. Current carbon storage. Carbon sequestered. Stormwater Attenuation (Avoided Runoff) i-Tree Eco also calculates Oxygen production of trees but these figures are reported herein.
Structural and Functional values	Replacement Cost in £. Carbon storage value in £. Carbon sequestration value in £. Pollution removal value in £. Avoided runoff in £

Table 8: Study Outputs.

The top ten species for each category were used for charts and tables within this report. However, all other figures are available within the iTree program. For a more detailed description of the model calculations see Appendix IV.

Tree Characteristics

Tree Species

13% of the 25,890 trees in the Camden inventory are Plane species (*Platanus spp*). The second, third and fourth most common trees are respectively: Common Lime (*Tilia x europaea)*, Sycamore (*Acer pseudoplatanus*) and Norway Maple (*Acer platanoides*).

The large diversity of tree species (258) within Camden creates the low percentages for the most common species observed in the chart and a high percentage for 'all other species'.

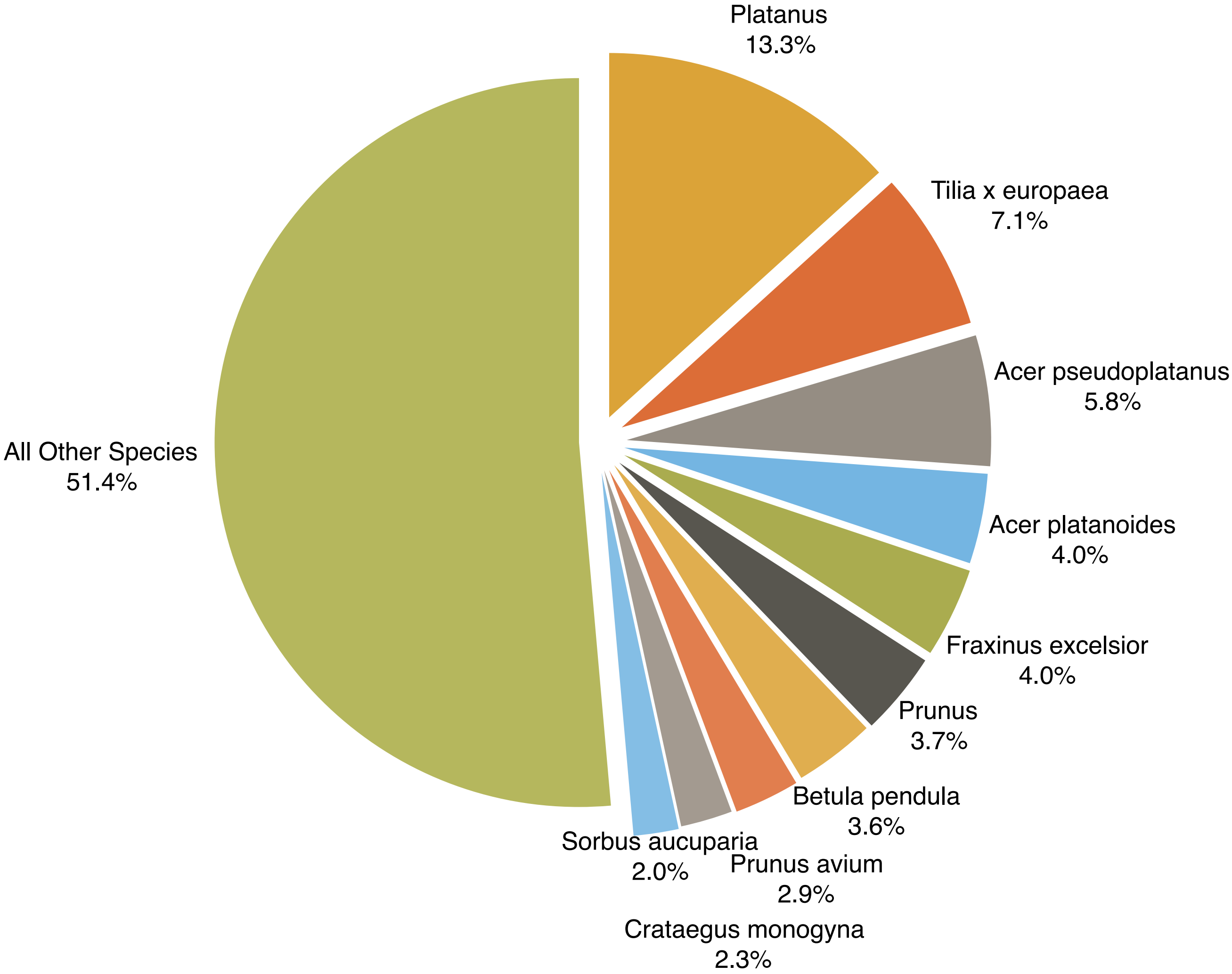

Figure 1: Percentage Population of Tree Species

Figure 2 illustrates how the tree population is made up when it is categorised by genus. Overall the chart indicates that there is a fairly well balanced tree diversity within Camden.

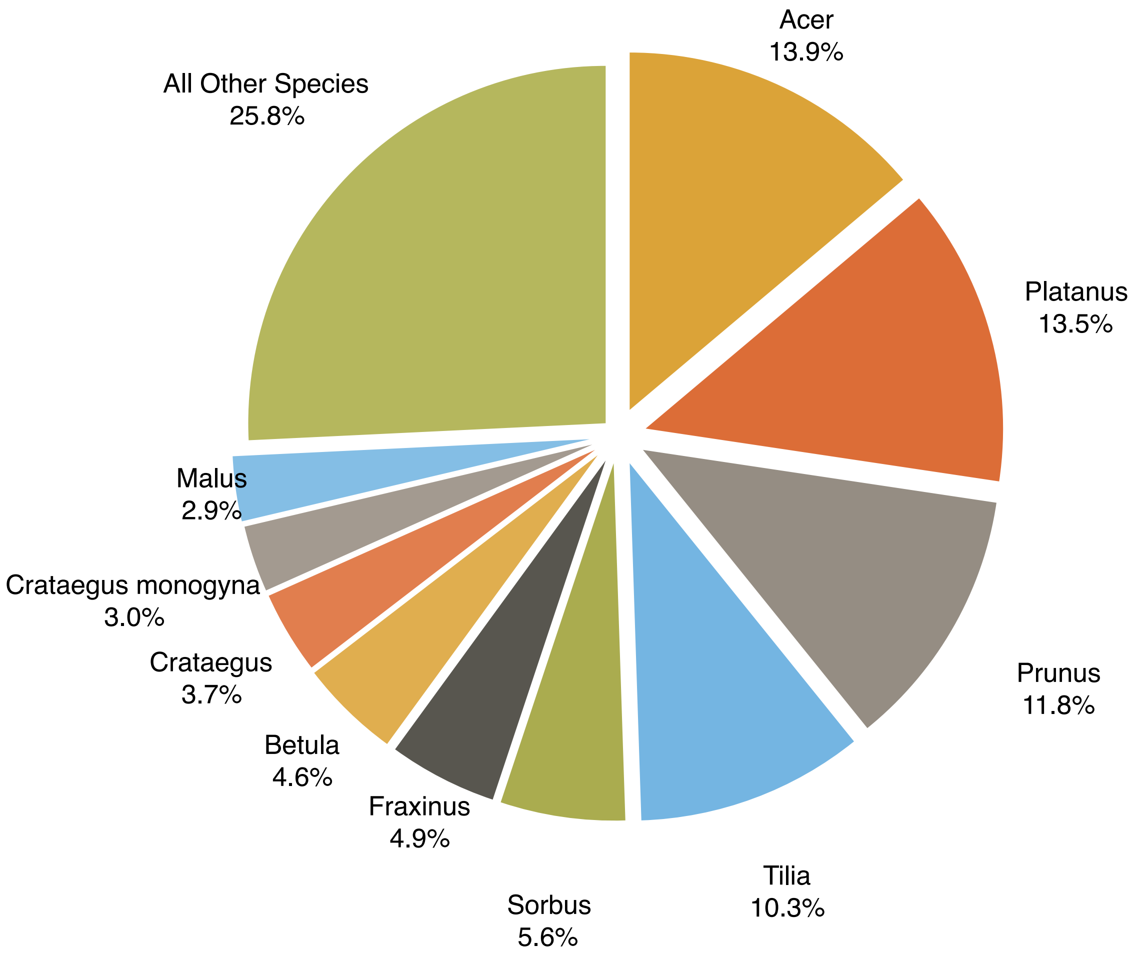

Figure 2: Percentage Population of Trees by Genus

Tree Diversity

Tree diversity is an important aspect of the tree population to take into account. Tree diversity increases overall resilience in the face of various environmental stress inducing factors [Including individual diversity within (i.e. genetic diversity of seedlings) and between species of trees in terms of different genera or families (i.e. *Acer* (maple family); *Ligustrum* (Olive family)].

A more diverse tree-scape is better able to deal with possible changes in climate or potential pest and disease impacts. The tree population within Camden represents a very diverse community of trees given the area, with 258 species of tree identified.

Tree species from 4 continents are represented in Camden, and as one might expect, most of the species are native to Europe (see figure 2 below).

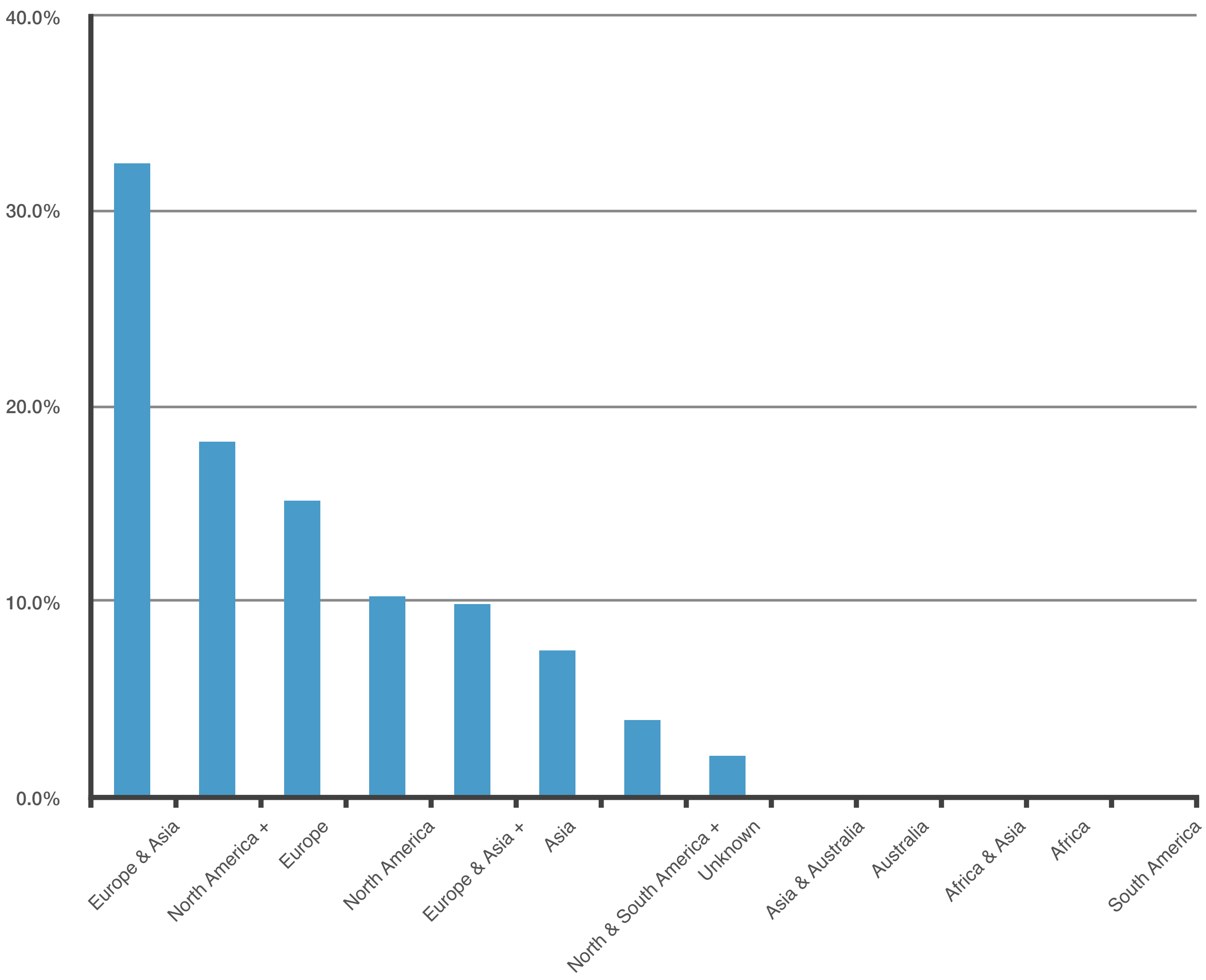

Figure 2: Origin of Tree Species

Note: The + sign indicates that the species is native to another continent other than the continents listed in the grouping. For example, Europe & Asia + would indicate that the species is native to Europe, Asia, and one other continent.

Size Distribution

Size class distribution is also an important aspect to consider in managing a sustainable and diverse 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.

In this survey trees were sized by their stem diameter at breast height (DBH) at 1.3m. Figure 3 (below) shows the percentage of tree population for the ten most common trees by DBH class.

The size class distribution of trees within Camden is well balanced in the lower size classes. However, the tree population would benefit from a greater diversity of large stature trees as this size class (Trees over 60cm DBH) is dominated by the London Plane (*Platanus spp*). Improved structural diversity would increase the overall resilience of the tree stock.

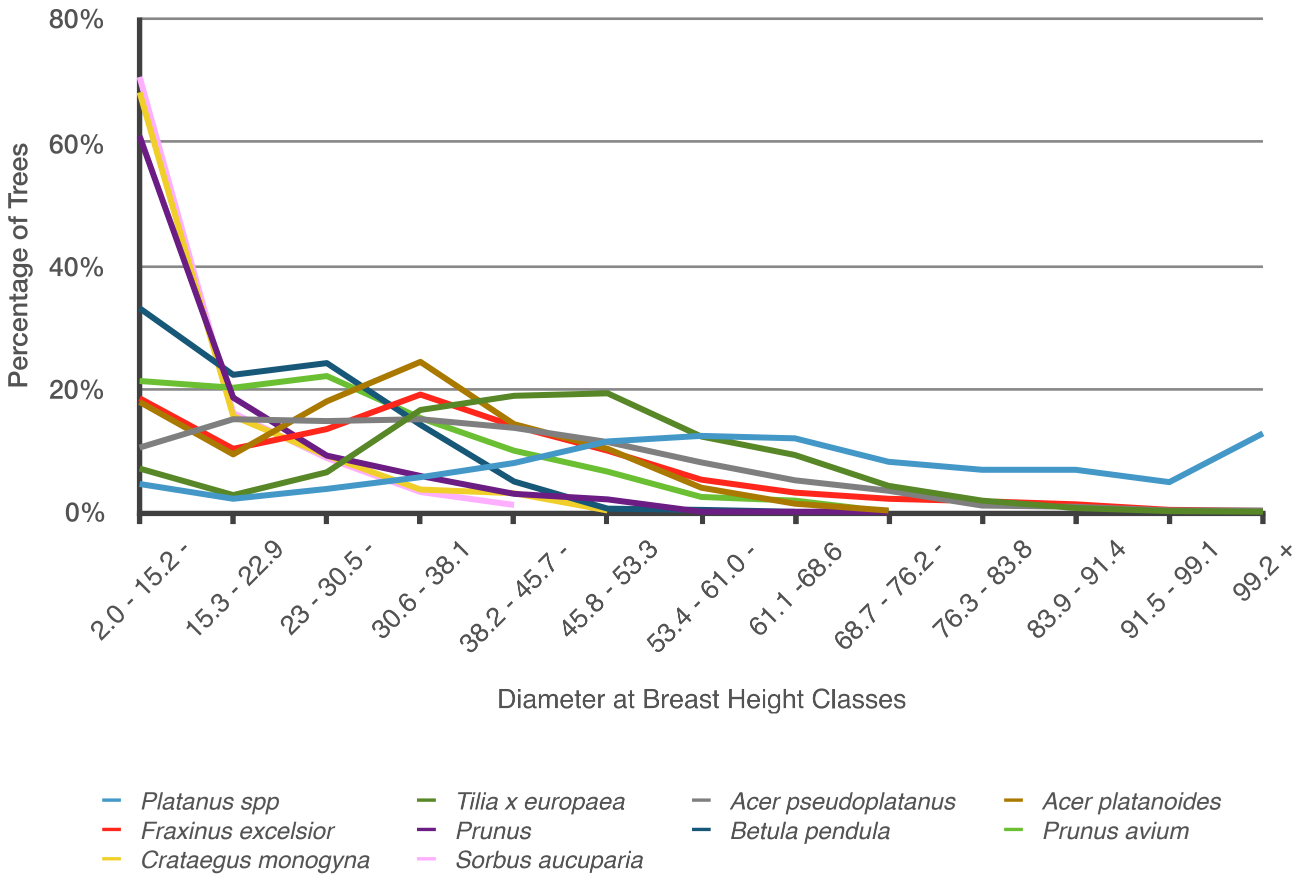

Figure 3: Percentage of tree population by DBH class

Leaf Area and Population

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

Within Camden, total leaf area is estimated at 5,116,000m². If all the layers of leaves within the tree canopies were spread out, they would cover an area nearly 3 times the size of Regents Park.

The three most dominant species in terms of leaf area are the *Platanus* (which has 40.6% of the total leaf area for all trees), *Tilia x europaea* (9.1%) and the *Acer pseudoplatanus* (3.9%).

Figure 4 (below) shows the top ten dominant trees' contributions to total leaf area. In total these 10 species, representing 45% of the trees, contribute 76% of the total leaf area. The remaining 55% of trees provide the other 24% of leaf area.

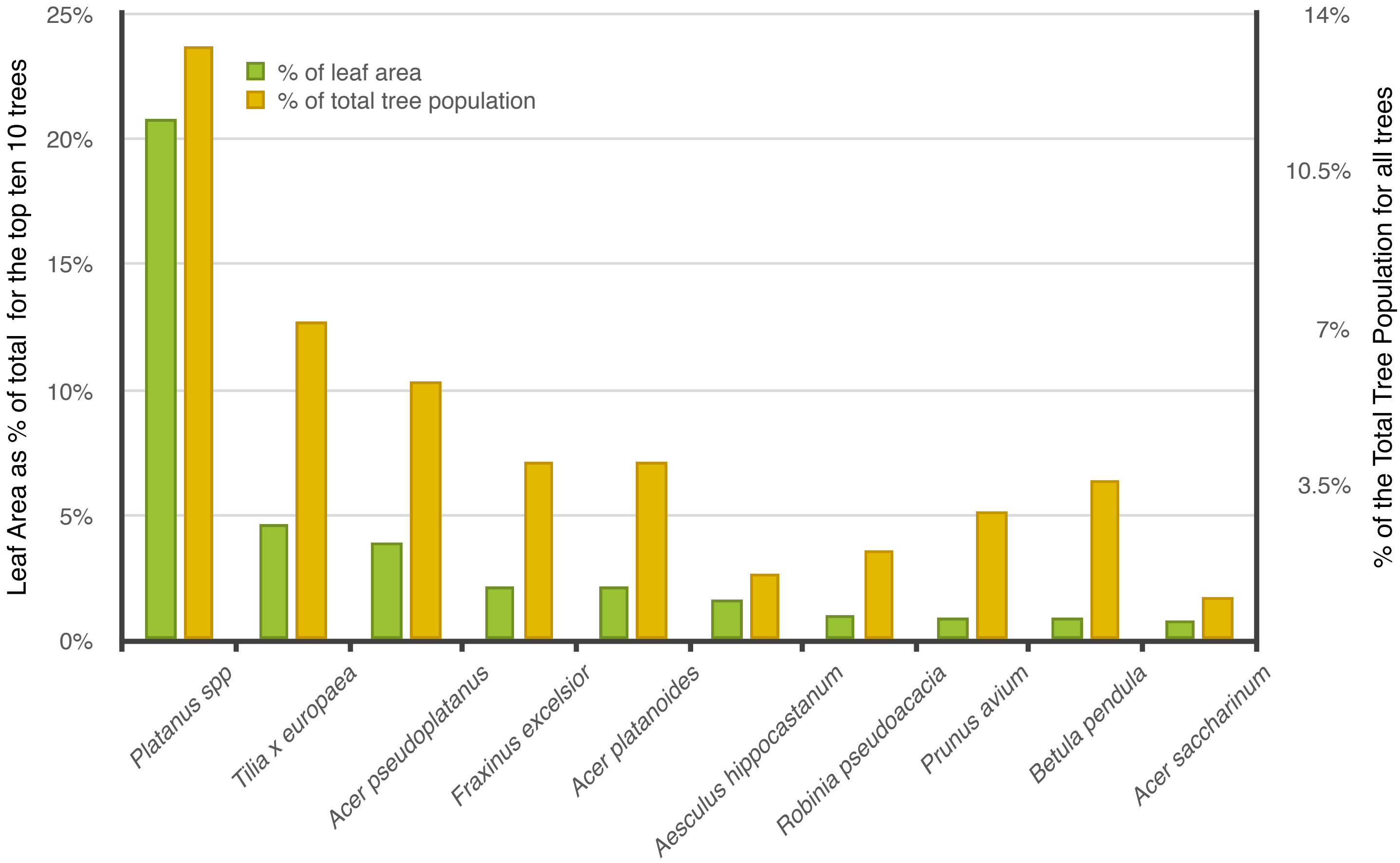

Figure 4: Percentage Leaf Area and Population of the Ten Most Dominant Trees

Results - Ecosystem Services Resource

Air Pollution Removal

Poor air quality is a common problem in many urban areas and along road networks. Air pollution caused by human activity has become a problem since the beginning of the industrial revolution. With the increase in population and industrialisation, large quantities of pollutants have been produced and released into the urban environment. The problems caused by poor air quality are well known, ranging from human health impacts to damage to buildings.

Urban trees can help to improve air quality by reducing air temperature and by directly removing pollutants from the air[5]. They intercept and absorb airborne pollutants through leaf surfaces[6]. In addition, by removing pollution from the atmosphere, trees reduce the risks of respiratory disease and asthma, thereby contributing to reduced health care costs[7].

The situation is complicated by the fact that trees also emit volatile organic compounds (VOCs) that can contribute to low-level ozone formation; however integrated studies have revealed that an increase in tree cover leads to a general reduction in ozone through a reduction in the urban heat island effect [8].

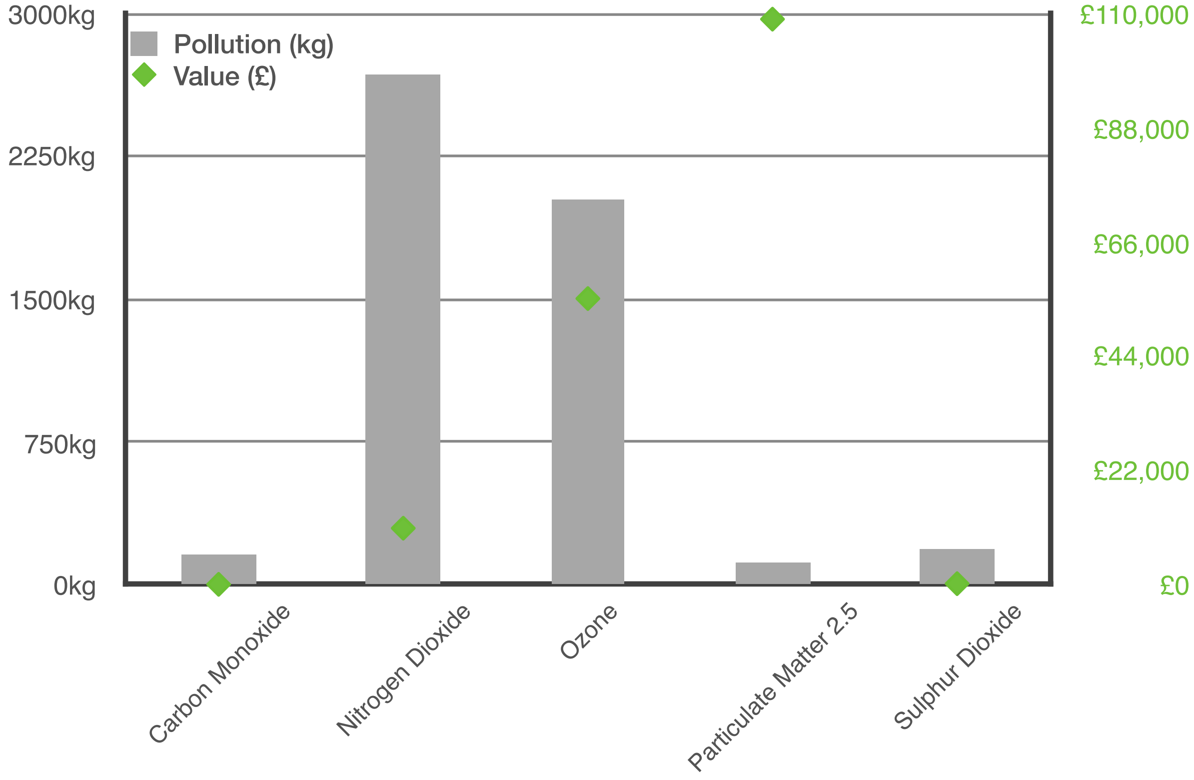

Figure 5: Value of the pollutants removed and quantity per-annum within Camden

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) is used as a substitution.

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5 Tiwary et al., 2009

6 Nowak et al., 2000

7 Peachey et al., 2009, Lovasi et al., 2008

8 Nowak et al.,2006

The i-Tree software accounts for both reduction and production of VOCs within its algorithms, and the overall effect of Camden's trees is to reduce ozone through evaporative cooling[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.

Figure 6 (below) shows the breakdown for the top ten pollution removing tree species in Camden. As different species can capture different sizes of particulate matter,[10] it is recommended that a broad range os species should be considered for planting in any air quality strategy.

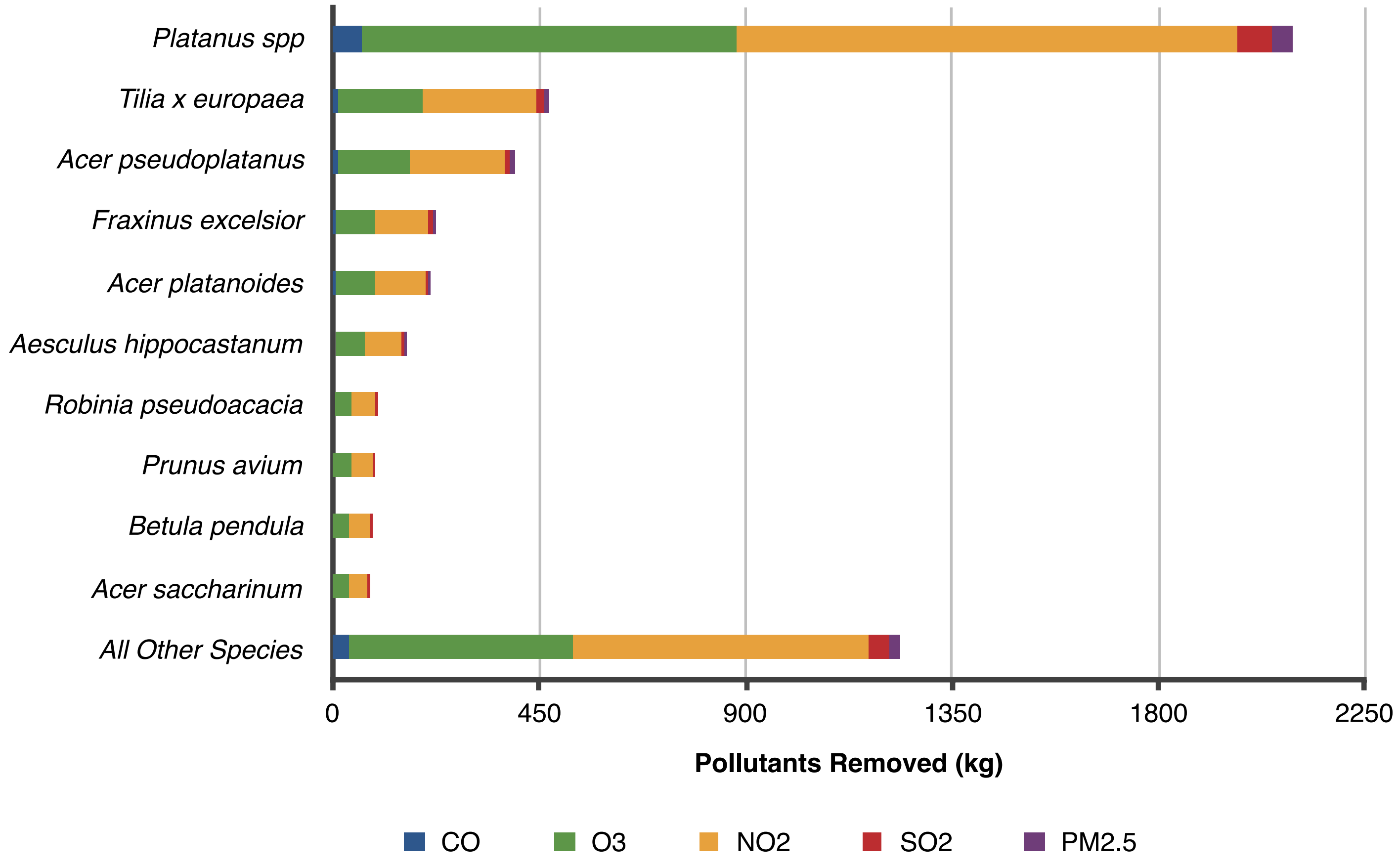

Figure 6: Pollution removal by tree species

[9] Escobedo and Nowak (2009)

[10] Freer-Smith et al (2005)

Carbon Storage

The main driving force behind climate change is the concentration of carbon dioxide (CO^2) in the atmosphere. Trees can help mitigate climate change by storing and sequestering atmospheric carbon as part of the carbon cycle. Since about 50% of wood by dry weight is comprised of carbon, tree stems and roots can store up carbon for decades or even centuries[11].

Over the lifetime of a tree, several tons of atmospheric carbon dioxide can be absorbed[12]. Overall the trees in the Camden inventory store 10,830 tonnes of carbon with a value of £691,300.00.

Figure 7 (below) illustrates the carbon storage of the top ten trees.

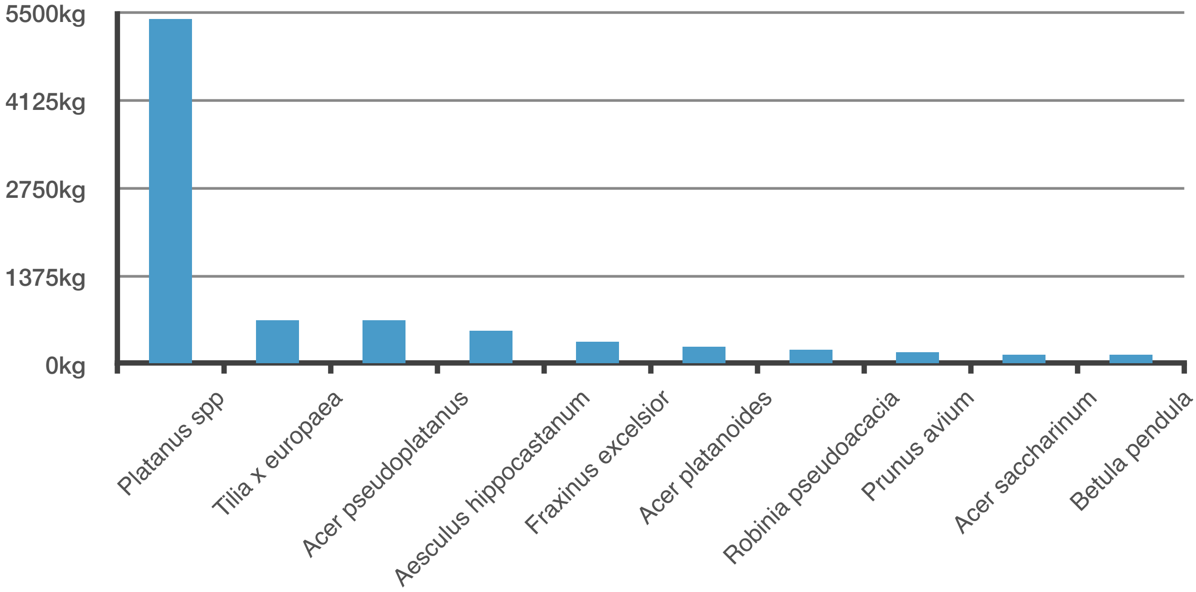

Figure 7: Carbon Storage(kg) for top ten tree species in Camden

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.

11 Kuhns 2008

12 McPherson 2007

Carbon Sequestration

Carbon sequestration is calculated from the predicted growth of the trees based on field measurements of the tree, climate data and genera specific growth rates within Eco. This provides a volume of tree growth. This volume is then converted into tonnes of carbon based on species specific conversion factors and then multiplied by the unit cost for carbon. The current UK social cost is £64 / tonne.

Camdens' inventory trees annually sequester 207 tonnes of carbon per year, with a value of £48,483. Table 9 (below) shows the ten trees that sequester the most Carbon per year and the value of the benefit derived from the sequestration of this atmospheric carbon.

Species	Carbon Sequestration (tonnes/yr)	Carbon Sequestration (£/yr)
Platanus spp	71.51	16777.96
Acer pseudoplatanus	14.61	3427.86
Tilia x europaea	14.57	3418.47
Acer platanoides	7.59	1780.80
Fraxinus excelsior	7.33	1719.79
Aesculus hippocastanum	6.97	1635.33
Prunus avium	5.82	1365.51
Betula pendula	5.29	1241.16
Robinia pseudoacacia	4.94	1159.04
Prunus spp	3.50	821.18
All Other Species	64.51	15135.59
Total	206.64	48482.70

Table 9: Carbon Sequestration by Species

Of the entire tree species inventoried, the *Platanus* species store and sequester the most carbon, adding 72 tonnes every year to the current *Platanus* carbon storage of 5410 tonnes.

Stormwater Run-off

Surface run-off can be a cause for concern in many areas as it can contribute to flooding and is a source of pollution in streams, wetlands, rivers, lakes, and oceans. During precipitation events, a portion of the precipitation is intercepted by vegetation (trees and shrubs) while a further portion reaches the ground. Precipitation that reaches the ground and does not infiltrate into the soil becomes surface runoff[13].

In urban areas, the large extent of impervious surfaces increases the amount of runoff. However, trees are very effective at reducing surface runoff[14]. Trees also intercept precipitation, while their root systems promote infiltration and storage in the soil.

Annual avoided surface runoff is calculated based on rainfall interception by vegetation, specifically the difference between annual runoff with and without vegetation. The trees within Camden help to reduce runoff by an estimated 6,740 m^3 a year with an associated value of £10,219.

Figure 8 shows the volumes and values for the ten most important species for reducing runoff.

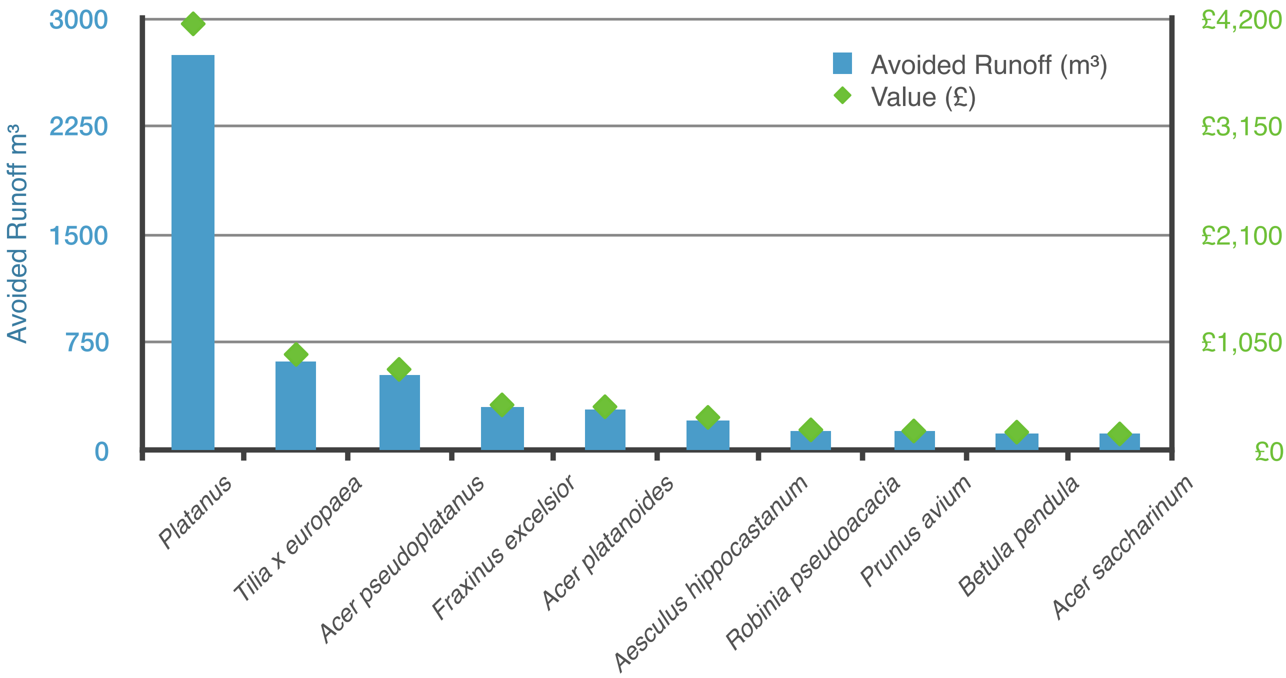

Figure 8: Avoided runoff by top ten species

The trees in Camden play an important role in reducing run-off: *Platanus* intercept a large proportion of the precipitation, reducing runoff more than all the other species. This is due to the trees population and canopy size.

6,739m^3 is equivalent to over 2.5 Olympic swimming pools of stormwater being averted every single year.

13 Hirabayashi 2012

14 Trees in Hard Landscapes 2014

Potential Pests and Diseases

Various insects and diseases can kill trees, reducing both their health and value, and therefore the sustainability of our urban forests. As most pests generally tend to have specific tree hosts, the potential damage that can be caused by each pest will differ.

In this instance Asian Long Horn Beetle (detected in this country for the first time in 2012) and Massaria disease of plane trees (a recent phenomenon in the UK) have been selected to illustrate how the results from this survey can be used to estimate the potential pest impacts on the trees in Camden.

These pathogens have the potential to reduce the health or kill a number of trees that are present in Camden. Figure 9 (below) illustrates the impact of these pathogens, the potential percentage of population that could become infected and those which are resistant.

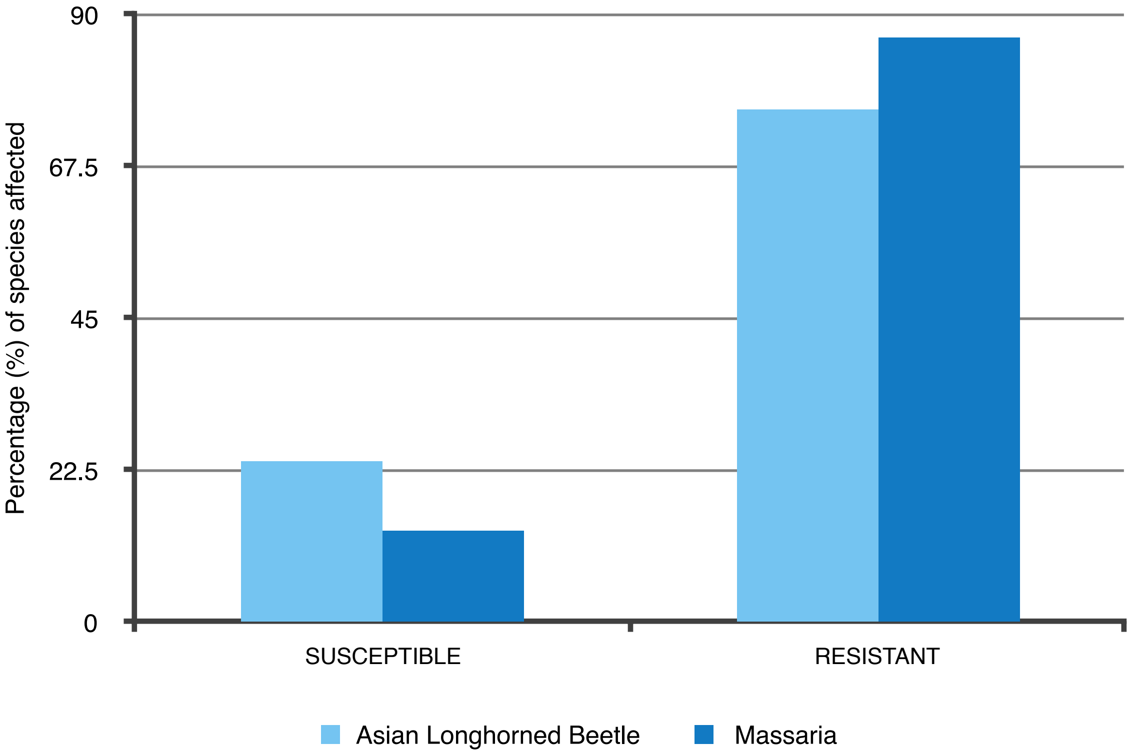

Figure 9: Potential Pest Impacts on Camdens' tree population

The Asian Longhorned beetle (ALB) is an insect that bores into and kills a wide range of hardwood species. This beetle could affect around 24% (or 6,187) of the trees in Camden. This beetle has only recently been found in the south east of England and originates from Asia. If the beetle were to become established in Britain there is likely to be extensive damage to both urban and woodland/forest trees.

Massaria disease was previously considered to be a weak parasite, and only capable of causing minor damage to trees. It is common in warmer Mediterranean climates and the southern United States. However, more recently it has been found attacking mature trees in the UK, causing branch death and rapid decay. As many of the affected trees have been street trees, the activity of this pathogen in causing branch dieback has resulted in a risk to public safety, and dead wood has to be removed before it becomes an unacceptable hazard[15].

Massaria disease has the potential to affect the plane trees within Camden and these trees account for 13.5% of the total tree population. Whilst massaria will only impact plane trees, the high replacement value will mean a disproportionate impact from their loss (see fig 10 below) furthermore, the plane trees are also delivering the majority of measured tree benefits within Camden.

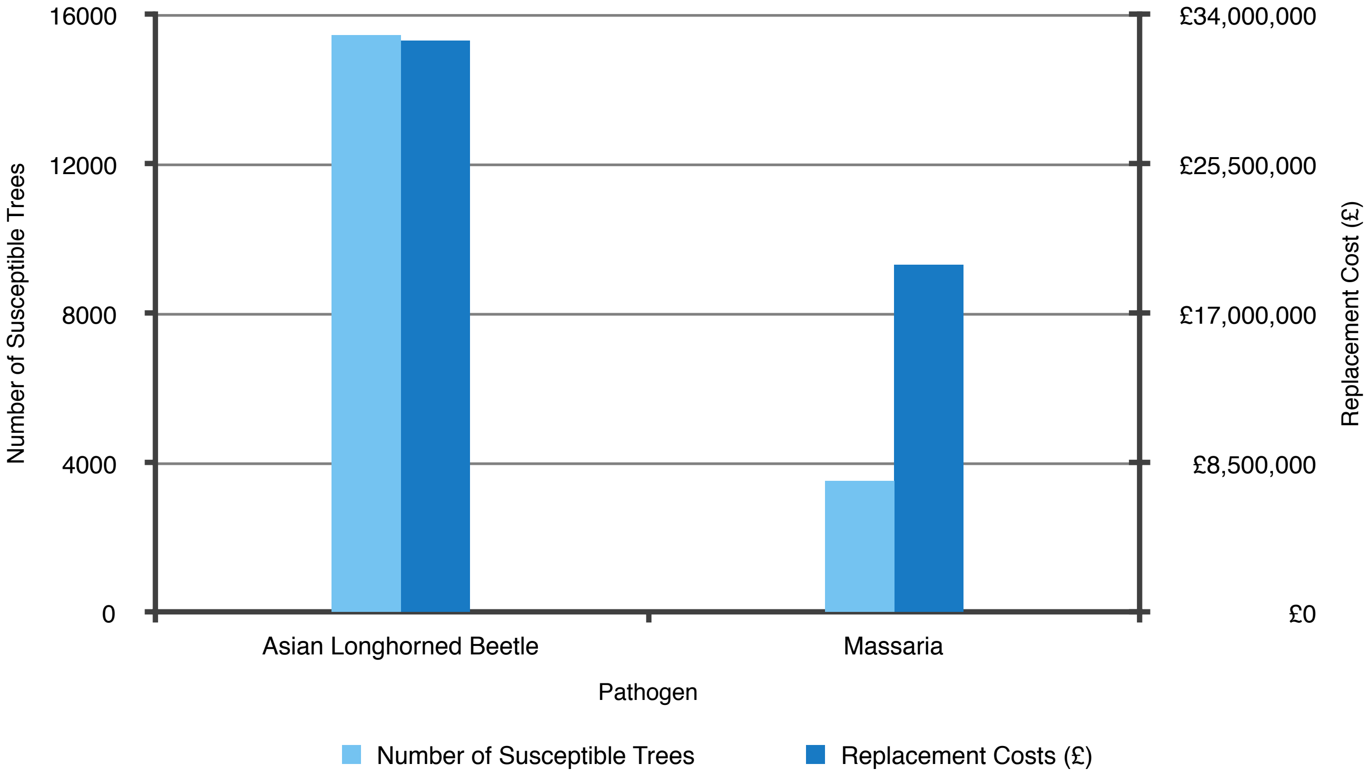

Figure 10: Potential Pest Impacts and Replacement Cost

[15] Tubby and Rose (2008)

Replacement Cost

In addition to estimating the environmental benefits provided by trees the i-Tree Eco model also provides a structural valuation which in the UK 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[16].

Replacement Cost is intended to provide a useful management tool, as it is able to value what it might cost to replace any or all of the trees (taking account of species suitability, depreciation and other economic considerations) should they become damaged or diseased for instance. The replacement costs for the ten most valuable tree species are shown in figure 11 below.

The total value of all trees in the study area currently stands at £43.5 million. *Platanus* is the most valuable species of tree, on account of both its size and population, followed by *Tilia x europaea* and *Acer pseudoplatanus*. These three species of tree account for £27 million (62%) of the total replacement cost of the trees in Camden

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

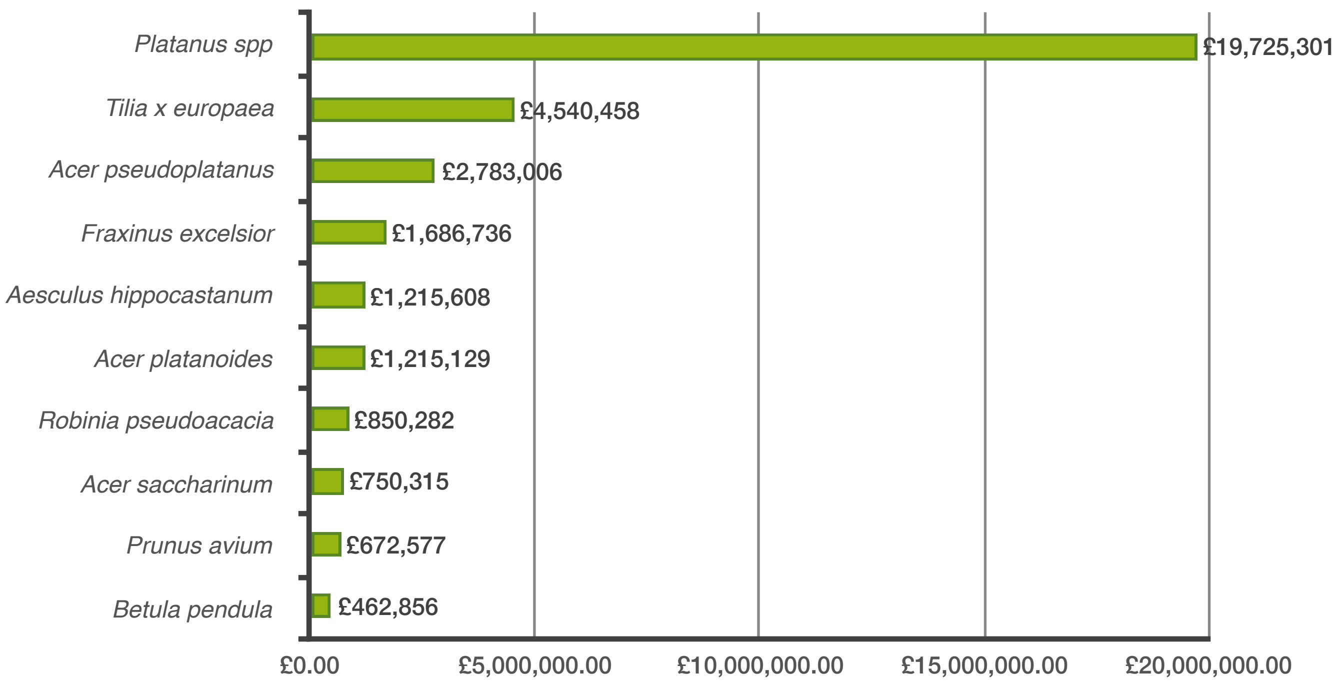

Figure 11: Replacement Cost for top ten trees in Camden

16 Hollis, 2007

Using this study

The results and data from previous i-Tree studies have been used in a variety of ways to improve management of trees and inform decision making. With better information we can make better decisions about how trees are managed to provide long term benefits to communities and this is one of the key benefits of undertaking a project such as this.

For example:

- Data can be used to inform species selection for increased tree diversity thereby lessening the impacts from potential threats like *Hymenoscyphus fraxineus* (formerly *Chalara fraxinea*) *or* Ash Dieback.
- Data can be used to produce educational and public information about Camden's trees (e.g. Tree tags).
- Using the data for cost benefit analysis to inform decision making.
- Update existing tree groups and woodland inventory data to allow for processing with iTree Eco v6
- Undertake a gap analysis to help inform where to plant trees to optimise ecosystem services and maximise the benefits, to align to the objectives and priorities of Camden's management plan.
- Size does matter! Identify trees that can grow on to full maturity and reach their optimal canopy size (given any site specific restrictions) and contribute the most benefits to the surrounding urban communities. Review together with an ancient tree management plan to include non-natives and heritage trees to broaden the potential for the Camden's trees to build resilience to future change.
- Stratify the inventory on a ward by ward basis, to highlight the areas where there is most need. The ward results could also be combined with ONS data on social deprivation or air pollution so that tree management could be prioritised and targeted.
- A full i-Tree Eco plot based survey across the borough would provide figures for both public and private trees in the urban forest. As a large percentage of the urban forest is in private ownership, but providing public benefit, information on this resource is crucial for strategic planning.

Conclusions

The tree population within Camden generally has a good species and age diversity. This will provide some resilience from possible future influences such as climate change and pest and disease outbreaks. The role of Camden's trees in complementing people's health is clear. Camden's trees provide a valuable public benefit - at least £199,000 in environmental services each year.

However, in terms of structural diversity the *Platanus* species have the largest proportion of trees in the larger size classes and all other tree species are poorly represented. Camden is highly dependant on this single species for the delivery of ecosystem services (13% of population, 40% of leaf area and 34% of all carbon stored in the trees). Camden would benefit from having a greater proportion of larger trees, of other species, in order to build resilience into its tree population.

Furthermore, the values presented in this study represent only a portion of the total value of the trees within Camden because only a proportion of the total benefits have been evaluated. Trees confer many other benefits, such as contributions to our health and well being that cannot yet be quantified and valued. Therefore, the values presented in this report should be seen as conservative estimates.

The extent of these benefits needs to be recognised, and strategies and policies that will serve to conserve this important resource (through education for example) would be one way to address this.

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 be maintained or increased. 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, multi-layered population.

Climate change could affect the tree stock in Camden in a variety of ways and there are great uncertainties about how this may manifest. Further study into this area would be useful in informing any long term tree and parkland strategies, such as species choice for example.

The challenge now is to ensure that policy makers and practitioners take full account of Camden's trees in decision making. Not only are trees a valuable functional component of our landscape they also make a significant contribution to peoples quality of life.

A follow-up report considering how Camden's trees could be fully considered in the Local Authority's decision making and a sustainable urban forest masterplan is recommended.

Appendix I. Relative Tree Effects

The trees in Camden provide benefits that include carbon storage and sequestration and air pollutant removal. To estimate the relative value of these benefits, tree benefits were compared to estimates of average carbon emissions and average family car emissions. These figures should be treated as a guideline only as they are largely based on US values (see footnotes).

Carbon storage is equivalent to:

- Annual carbon (C) emissions from 8,440 family cars
- Annual C emissions from 3,460 single-family houses

Carbon monoxide removal is equivalent to:

- Annual carbon monoxide emissions from 2 family cars
- Annual carbon monoxide emissions from 4 single-family houses

Nitrogen dioxide removal is equivalent to:

- Annual nitrogen dioxide emissions from 423 family cars
- Annual nitrogen dioxide emissions from 191 single-family houses

Sulphur dioxide removal is equivalent to:

- Annual sulphur dioxide emissions from 2,270 family cars
- Annual sulphur dioxide emissions from 6 single-family houses

Carbon sequestration is equivalent to:

- Annual carbon (C) emissions from 200 family cars
- Annual C emissions from 100 single-family houses

Average passenger automobile emissions per mile were based on dividing total 2002 pollutant emissions from light-duty gas vehicles (National Emission Trends http://www.epa.gov/ttn/chief/trends/index.html) divided by total miles driven in 2002 by passenger cars (National Transportation Statistics http://www.bts.gov/publications/national_transportation_statistics/2004/).

Average annual passenger automobile emissions per vehicle were based on dividing total 2002 pollutant emissions from light-duty gas vehicles by total number of passenger cars in 2002 (National Transportation Statistics http://www.bts.gov/publications/national_transportation_statistics/2004/).

Carbon dioxide emissions from automobile assumed six pounds of carbon per gallon of gasoline if energy costs of refinement and transportation are included (Graham, R.L., Wright, L.L., and Turhollow, A.F. 1992. The potential for short-rotation woody crops to reduce U.S. CO2 Emissions. Climatic Change 22:223-238).

Appendix II. Species Importance Ranking List

Species	Percent Population	Percent Leaf Area	Importance Value
Platanus spp	13.30	40.60	53.90
Tilia x europaea	7.10	9.10	16.20
Acer pseudoplatanus	5.80	7.70	13.50
Fraxinus excelsior	4.00	4.30	8.30
Acer platanoides	4.00	4.10	8.10
Betula pendula	3.60	1.70	5.30
Prunus avium	2.90	1.80	4.70
Aesculus hippocastanum	1.50	3.10	4.60
Prunus	3.70	0.80	4.50
Robinia pseudoacacia	2.00	1.90	3.90
Ilex aquifolium	2.00	0.80	2.80
Crataegus monogyna	2.30	0.50	2.80
Acer campestre	2.00	0.80	2.80
Acer saccharinum	1.00	1.50	2.60
Tilia euchlora	1.40	1.10	2.50
Sorbus aria	1.60	0.80	2.40
Sorbus aucuparia	2.00	0.40	2.40
Malus	2.00	0.30	2.30
Prunus cerasifera	1.60	0.60	2.20
Taxus baccata	0.90	0.90	1.80
Tilia cordata	0.90	0.90	1.80
Ailanthus altissima	0.70	1.00	1.70
Sambucus nigra	1.30	0.40	1.70
Ilex altaclarensis	1.00	0.50	1.40
Prunus subhirtella	1.20	0.10	1.30
Chamaecyparis lawsoniana	0.90	0.40	1.30
Amelanchier	1.20	0.10	1.30
Alnus cordata	0.70	0.50	1.20
Fraxinus oxycarpa	0.60	0.60	1.20
Sorbus	1.00	0.20	1.20
Fagus sylvatica	0.40	0.70	1.20

Species	Percent Population	Percent Leaf Area	Importance Value
Crataegus	1.00	0.20	1.20
Carpinus betulus	0.70	0.40	1.10
Quercus robur	0.50	0.50	1.00
Sorbus intermedia	0.70	0.20	0.90
Pyrus calleryana 'Chanticleer'	0.70	0.10	0.90
Prunus padus	0.60	0.30	0.90
Ginkgo biloba	0.70	0.10	0.80
Prunus laurocerasus	0.60	0.30	0.80
Tilia platyphyllos	0.40	0.40	0.80
Malus domestica	0.60	0.10	0.70
Carpinus betulus 'fastigiata'	0.40	0.30	0.70
Betula	0.50	0.10	0.70
Alnus glutinosa	0.40	0.20	0.60
Acer negundo	0.30	0.30	0.60
Liquidambar styraciflua	0.60	0.10	0.60
Laurus nobilis	0.40	0.20	0.60
Tilia	0.30	0.30	0.60
Aesculus x carnea	0.30	0.30	0.60
Salix alba	0.30	0.30	0.60
Pyrus communis	0.40	0.20	0.50
Quercus rubra	0.20	0.30	0.50
Betula papyrifera	0.40	0.10	0.50
Acer	0.30	0.20	0.50
Pyrus	0.40	0.10	0.50
Betula pubescens	0.30	0.20	0.50
Corylus avellana	0.40	0.10	0.50
Cupressocyparis leylandii	0.30	0.10	0.50
Salix caprea	0.30	0.20	0.50
Quercus Quercus/live ilex	0.30	0.20	0.50
Salix fragilis	0.10	0.30	0.40
Photinia x fraseri	0.40	<0.10	0.40
Tilia tomentosa	0.20	0.20	0.40
Platanus orientalis	0.20	0.20	0.40

Species	Percent Population	Percent Leaf Area	Importance Value
Prunus serrulata	0.30	0.10	0.40
Malus tschonoskii	0.30	0.10	0.40
Liriodendron tulipifera	0.30	0.10	0.40
Fraxinus ornus	0.30	0.10	0.40
Prunus lusitanica	0.30	0.10	0.40
Laburnum anagyroides	0.20	0.10	0.40
Gleditsia triacanthos	0.20	0.10	0.30
Fagus sylvatica 'purpurea'	0.10	0.20	0.30
Castanea sativa	0.20	0.10	0.30
Corylus colurna	0.20	0.10	0.30
Magnolia	0.30	0.10	0.30
Populus nigra 'italica'	0.20	0.10	0.30
Populus nigra	0.10	0.20	0.30
Catalpa bignonioides	0.20	0.10	0.30
Acer cappadocicum	0.10	0.10	0.30
Alnus incana	0.20	0.10	0.20
Cotoneaster	0.20	0.10	0.20
Syringa vulgaris	0.20	<0.10	0.20
Prunus serrula	0.20	<0.10	0.20
Ulmus glabra	0.20	0.10	0.20
Cotoneaster frigidus	0.20	0.10	0.20
Ligustrum lucidum	0.20	<0.10	0.20
Amelanchier arborea	0.20	<0.10	0.20
Prunus domestica	0.20	<0.10	0.20
Crataegus x lavallei	0.20	<0.10	0.20
Cupressus	0.20	<0.10	0.20
Chamaecyparis	0.20	<0.10	0.20
Fraxinus	0.10	0.10	0.20
Populus tremula	0.10	0.10	0.20
Juglans regia	0.10	0.10	0.20
Prunus sargentii	0.20	<0.10	0.20
Betula utilis	0.20	<0.10	0.20
Parrotia persica	0.10	0.10	0.20

Species	Percent Population	Percent Leaf Area	Importance Value
Quercus cerris	0.10	0.10	0.20
Sorbus x thuringiaca	0.10	<0.10	0.20
Ulmus	0.20	<0.10	0.20
Pinus nigra	0.10	0.10	0.20
Salix babylonica	0.10	0.10	0.20
Ulmus procera	0.10	0.10	0.20
Eucalyptus	0.10	0.10	0.20
Acer rubrum	0.10	<0.10	0.20
Pinus sylvestris	0.10	<0.10	0.20
Crataegus laevigata	0.10	<0.10	0.20
Prunus dulcis	0.10	<0.10	0.20
Ficus carica	0.10	<0.10	0.10
Amelanchier alnifolia	0.10	<0.10	0.10
Crataegus crus-galli	0.10	<0.10	0.10
Eriobotrya japonica	0.10	<0.10	0.10
Populus alba	0.10	0.10	0.10
Sorbus hupehensis	0.10	<0.10	0.10
Prunus fruticosa	0.10	<0.10	0.10
Eucalyptus gunnii	0.10	<0.10	0.10
Koelreuteria paniculata	0.10	<0.10	0.10
Tamarix tetragyna	0.10	<0.10	0.10
Ulmus carpinifolia 'Hollandica'	0.10	<0.10	0.10
Crataegus prunifolia	0.10	<0.10	0.10
Ostrya carpinifolia	0.10	<0.10	0.10
Betula ermanii	0.10	<0.10	0.10
Rhus	0.10	<0.10	0.10
Cedrus libani	<0.10	0.10	0.10
Sorbus sargentiana	0.10	<0.10	0.10
Alnus rubra	0.10	<0.10	0.10
Betula albo-sinensis	0.10	<0.10	0.10
Zelkova serrata	0.10	<0.10	0.10
Betula nigra	0.10	<0.10	0.10
Picea abies	<0.10	<0.10	0.10

Species	Percent Population	Percent Leaf Area	Importance Value
Acer griseum	0.10	<0.10	0.10
Cedrus atlantica glauca	<0.10	<0.10	0.10
Ligustrum ovalifolium	0.10	<0.10	0.10
Quercus palustris	0.10	<0.10	0.10
Quercus robur 'fastigiata'	0.10	<0.10	0.10
Cornus	0.10	<0.10	0.10
Morus nigra	<0.10	<0.10	0.10
Metasequoia glyptostroboides	<0.10	<0.10	0.10
Malus sylvestris	0.10	<0.10	0.10
Acer palmatum	<0.10	<0.10	0.10
Acer davidii	0.10	<0.10	0.10
Pyrus salicifolia	0.10	<0.10	0.10
Sophora japonica	0.10	<0.10	0.10
Olea europaea	0.10	<0.10	0.10
Malus floribunda	0.10	<0.10	0.10
Taxodium distichum	<0.10	<0.10	0.10
Ilex	<0.10	<0.10	0.10
Amelanchier canadensis	0.10	<0.10	0.10
Taxus	<0.10	<0.10	0.10
Pterocarya fraxinifolia	<0.10	<0.10	0.10
Cupressus macrocarpa	<0.10	<0.10	0.10
Salix matsudana	<0.10	<0.10	<0.10
Sorbus torminalis	<0.10	<0.10	<0.10
Cornus mas	<0.10	<0.10	<0.10
Juglans nigra	<0.10	<0.10	<0.10
Cercis siliquastrum	<0.10	<0.10	<0.10
Lagerstroemia indica	<0.10	<0.10	<0.10
Nothofagus obliqua	<0.10	<0.10	<0.10
Clerodendrum trichotomum	<0.10	<0.10	<0.10
Thuja plicata	<0.10	<0.10	<0.10
Amelanchier laevis	<0.10	<0.10	<0.10
Cedrus deodara	<0.10	<0.10	<0.10
Laburnum x watereri	<0.10	<0.10	<0.10

Species	Percent Population	Percent Leaf Area	Importance Value
Magnolia kobus	<0.10	<0.10	<0.10
Populus balsamifera	<0.10	<0.10	<0.10
Acacia dealbata	<0.10	<0.10	<0.10
Juniperus	<0.10	<0.10	<0.10
Euonymus europaea	<0.10	<0.10	<0.10
Cercis canadensis	<0.10	<0.10	<0.10
Tilia cordata 'greenspire'	<0.10	<0.10	<0.10
Hamamelis	<0.10	<0.10	<0.10
Populus	<0.10	<0.10	<0.10
Acer platanoides 'Schwedleri'	<0.10	<0.10	<0.10
Prunus spinosa	<0.10	<0.10	<0.10
Quercus coccinea	<0.10	<0.10	<0.10
Arbutus unedo	<0.10	<0.10	<0.10
Aesculus indica	<0.10	<0.10	<0.10
Tilia americana	<0.10	<0.10	<0.10
Alnus viridis	<0.10	<0.10	<0.10
Fraxinus americana	<0.10	<0.10	<0.10
Acer saccharum	<0.10	<0.10	<0.10
Pittosporum tenuifolium	<0.10	<0.10	<0.10
Cedrus atlantica	<0.10	<0.10	<0.10
Ulmus x hollandica	<0.10	<0.10	<0.10
Nothofagus antarctica	<0.10	<0.10	<0.10
Paulownia tomentosa	<0.10	<0.10	<0.10
Sorbus commixta	<0.10	<0.10	<0.10
Salix x chrysocoma	<0.10	<0.10	<0.10
Larix decidua	<0.10	<0.10	<0.10
Hibiscus	<0.10	<0.10	<0.10
Salix	<0.10	<0.10	<0.10
Quercus petraea	<0.10	<0.10	<0.10
Yucca	<0.10	<0.10	<0.10
Davidia involucrata	<0.10	<0.10	<0.10
Cordyline australis	<0.10	<0.10	<0.10
Abies	<0.10	<0.10	<0.10

Species	Percent Population	Percent Leaf Area	Importance Value
Aesculus flava	<0.10	<0.10	<0.10
Cercidiphyllum japonicum	<0.10	<0.10	<0.10
Ligustrum vulgare	<0.10	<0.10	<0.10
Pinus wallichiana	<0.10	<0.10	<0.10
Acer rubrum 'armstrong'	<0.10	<0.10	<0.10
Acer japonicum	<0.10	<0.10	<0.10
Acer ginnala	<0.10	<0.10	<0.10
Picea	<0.10	<0.10	<0.10
Prunus maackii	<0.10	<0.10	<0.10
Acer x freemanii	<0.10	<0.10	<0.10
Mespilus germanica	<0.10	<0.10	<0.10
Nyssa sylvatica	<0.10	<0.10	<0.10
Viburnum tinus	<0.10	<0.10	<0.10
Quercus	<0.10	<0.10	<0.10
Cornus kousa	<0.10	<0.10	<0.10
Griselinia littoralis	<0.10	<0.10	<0.10
Pinus	<0.10	<0.10	<0.10
Sorbus americana	<0.10	<0.10	<0.10
Sorbus vilmorinii	<0.10	<0.10	<0.10
Morus alba	<0.10	<0.10	<0.10
Araucaria araucana	<0.10	<0.10	<0.10
Buddleja davidii	<0.10	<0.10	<0.10
Juniperus communis	<0.10	<0.10	<0.10
Liquidambar	<0.10	<0.10	<0.10
Eucommia ulmoides	<0.10	<0.10	<0.10
Tetradium daniellii	<0.10	<0.10	<0.10
Celtis occidentalis	<0.10	<0.10	<0.10
Magnolia grandiflora	<0.10	<0.10	<0.10
Carya illinoinensis	<0.10	<0.10	<0.10
Juniperus chinensis	<0.10	<0.10	<0.10
Betula maximowicziana	<0.10	<0.10	<0.10
Catalpa speciosa	<0.10	<0.10	<0.10
Sequoiadendron giganteum	<0.10	<0.10	<0.10

Species	Percent Population	Percent Leaf Area	Importance Value
Pinus radiata	<0.10	<0.10	<0.10
Fraxinus angustifolia	<0.10	<0.10	<0.10
Pseudotsuga menziesii	<0.10	<0.10	<0.10
Quercus hispanica	<0.10	<0.10	<0.10
Magnolia wilsonii	<0.10	<0.10	<0.10
Cornus florida	<0.10	<0.10	<0.10
Cryptomeria japonica	<0.10	<0.10	<0.10
Zelkova carpinifolia	<0.10	<0.10	<0.10
Trachycarpus fortunei	<0.10	<0.10	<0.10
Abies concolor	<0.10	<0.10	<0.10
Chamaecyparis nootkatensis	<0.10	<0.10	<0.10
Picea pungens	<0.10	<0.10	<0.10
Casuarina equisetifolia	<0.10	<0.10	<0.10
Rhamnus cathartica	<0.10	<0.10	<0.10
Rhododendron	<0.10	<0.10	<0.10
Abies alba	<0.10	<0.10	<0.10
Sequoia sempervirens	<0.10	<0.10	<0.10
Pinus strobus	<0.10	<0.10	<0.10
Gymnocladus dioicus	<0.10	<0.10	<0.10
Pseudopanax	<0.10	<0.10	<0.10
Acer rubrum 'red sunset'	<0.10	<0.10	<0.10
Broussonetia papyrifera	<0.10	<0.10	<0.10
Alnus	<0.10	<0.10	<0.10
Carpinus japonica	<0.10	<0.10	<0.10
Cladrastis kentukea	<0.10	<0.10	<0.10
Fremontodendron californicum	<0.10	<0.10	<0.10
Liriodendron tulipifera Fastigiatum	<0.10	<0.10	<0.10
Elaeagnus angustifolia	<0.10	<0.10	<0.10
Quercus castaneifolia	<0.10	<0.10	<0.10

Appendix III. Tree Values by Species

Species	Trees	Carbon Storage (Tonnes)	Gross Carbon Seq (Tonnes/Yr)	Avoided Runoff (m³/Yr)	Pollution Removal (Tonne/Yr)	Replacement Cost (£)
Platanus spp	3456	5411.61	71.51	2733.28	2.09	£19,725,301.40
Tilia x europaea	1827	695.26	14.57	613.63	0.47	£4,540,458.24
Acer pseudoplatanus	1505	674.82	14.61	517.77	0.40	£2,783,005.96
Fraxinus excelsior	1026	336.46	7.33	290.00	0.22	£1,686,736.42
Aesculus hippocastanum	377	508.97	6.97	209.90	0.16	£1,215,607.67
Acer platanoides	1028	284.28	7.59	278.14	0.21	£1,215,129.10
Robinia pseudoacacia	511	207.31	4.94	129.96	0.10	£850,281.69
Acer saccharinum	267	144.90	2.57	103.90	0.08	£750,314.91
Prunus avium	747	185.99	5.82	122.87	0.09	£672,576.55
Betula pendula	941	128.70	5.29	115.26	0.09	£462,855.76
Tilia cordata	239	71.63	1.57	60.24	0.05	£457,186.05
Sorbus aria	420	95.57	3.01	55.20	0.04	£419,923.41
Ailanthus altissima	181	105.36	2.31	67.45	0.05	£389,743.29
Tilia euchlora	351	58.85	1.67	75.83	0.06	£379,684.94
Populus nigra 'italica'	49	83.40	1.10	7.55	0.01	£351,906.84
Taxus baccata	245	44.62	0.85	58.88	0.05	£344,400.42
Alnus cordata	180	81.93	1.93	35.57	0.03	£342,039.54
Fagus sylvatica	112	96.90	1.66	50.43	0.04	£334,801.48
Quercus robur	140	85.97	1.48	31.76	0.02	£275,546.30
Tilia platyphyllos	93	41.27	0.83	28.18	0.02	£274,915.15
Prunus	948	82.50	3.50	55.99	0.04	£266,582.45
Populus nigra	33	57.26	0.72	10.91	0.01	£221,895.73
Acer campestre	514	51.41	1.96	52.66	0.04	£219,276.28
Fraxinus oxycarpa	146	39.57	1.02	43.45	0.03	£197,472.75
Salix alba	72	49.32	0.92	19.42	0.01	£193,079.78
Sorbus intermedia	172	36.42	1.18	15.46	0.01	£163,694.41
Prunus cerasifera	407	64.20	2.39	42.01	0.03	£159,391.76
Aesculus x carnea	69	37.89	0.80	20.36	0.02	£156,021.52
Quercus rubra	61	41.64	0.81	19.48	0.01	£151,779.40
Ilex aquifolium	518	40.70	1.99	54.84	0.04	£148,590.67

Species	Trees	Carbon Storage (Tonnes)	Gross Carbon Seq (Tonnes/ Yr)	Avoided Runoff (m^3/Yr)	Pollution Removal (Tonne/ Yr)	Replacement Cost (£)
Ilex altaclarensis	247	34.21	1.39	30.39	0.02	£141,780.86
Carpinus betulus	181	29.72	0.95	26.98	0.02	£129,078.77
Fagus sylvatica 'purpurea'	26	37.52	0.53	16.26	0.01	£128,392.92
Crataegus monogyna	589	33.60	1.72	34.64	0.03	£126,397.27
Platanus orientalis	39	30.54	0.48	16.67	0.01	£121,027.12
Tilia	84	17.70	0.46	17.02	0.01	£119,444.97
Carpinus betulus 'fastigiata'	103	26.77	0.76	19.44	0.01	£113,467.93
Malus	513	22.38	0.98	20.78	0.02	£107,845.05
Prunus padus	155	29.81	1.08	17.63	0.01	£107,316.62
Quercus Quercus/live ilex	71	30.02	0.74	12.23	0.01	£106,036.56
Pyrus communis	99	23.53	0.69	10.59	0.01	£101,347.05
Alnus glutinosa	106	24.24	0.70	15.90	0.01	£98,848.56
Sorbus	247	22.83	0.92	15.32	0.01	£98,251.70
Sorbus aucuparia	521	21.65	1.22	24.09	0.02	£97,308.52
Chamaecyparis lawsoniana	239	17.81	0.56	23.85	0.02	£93,814.96
Acer negundo	81	22.09	0.60	20.94	0.02	£92,783.55
Tilia tomentosa	58	12.31	0.36	12.56	0.01	£87,650.16
Salix babylonica	22	22.12	0.37	5.52	<0.01	£86,984.26
Sambucus nigra	328	20.74	0.98	28.50	0.02	£84,607.35
Pinus nigra	19	9.24	0.15	6.71	0.01	£75,848.83
Castanea sativa	47	17.85	0.42	9.78	0.01	£74,722.06
Quercus cerris	19	20.93	0.39	7.87	0.01	£70,948.00
Salix fragilis	38	15.86	0.38	18.85	0.01	£68,444.29
Gleditsia triacanthos	58	18.20	0.46	7.99	0.01	£66,655.21
Acer	73	15.61	0.46	14.97	0.01	£64,305.57
Ginkgo biloba	187	13.79	0.47	7.50	0.01	£59,597.00
Salix caprea	77	14.57	0.43	11.27	0.01	£57,961.10
Catalpa bignonioides	46	15.65	0.37	5.37	<0.01	£57,369.11
Laurus nobilis	101	14.15	0.46	13.24	0.01	£54,024.67
Acer cappadocicum	33	12.03	0.29	8.68	0.01	£52,193.08
Betula pubescens	77	13.60	0.53	12.58	0.01	£51,154.30
Pyrus calleryana 'Chanticleer'	193	12.39	0.66	8.39	0.01	£48,425.48

Species	Trees	Carbon Storage (Tonnes)	Gross Carbon Seq (Tonnes/ Yr)	Avoided Runoff (m^3/Yr)	Pollution Removal (Tonne/ Yr)	Replacement Cost (£)
Fraxinus ornus	69	9.11	0.31	6.99	0.01	£48,303.73
Crataegus	249	13.72	0.77	13.36	0.01	£47,658.44
Prunus laurocerasus	146	14.20	0.66	18.08	0.01	£45,948.36
Betula papyrifera	93	12.81	0.57	9.97	0.01	£45,585.85
Populus alba	13	7.93	0.15	4.22	<0.01	£38,075.91
Corylus colurna	59	8.14	0.30	5.87	<0.01	£37,240.61
Fraxinus	25	7.08	0.18	7.59	0.01	£36,624.78
Prunus subhirtella	306	7.78	0.53	9.87	0.01	£36,196.80
Juglans regia	23	7.78	0.20	7.70	0.01	£35,016.41
Malus domestica	149	7.85	0.40	8.38	0.01	£34,966.79
Cedrus libani	6	4.69	0.05	4.11	<0.01	£32,492.95
Prunus serrulata	69	9.95	0.35	8.57	0.01	£32,127.60
Pyrus	111	7.50	0.37	4.35	<0.01	£29,643.27
Sorbus x thuringiaca	36	6.75	0.24	2.96	<0.01	£29,401.27
Populus tremula	31	5.17	0.17	5.85	<0.01	£29,219.20
Populus	5	7.11	0.11	0.78	<0.01	£27,421.46
Amelanchier	310	2.26	0.30	4.14	<0.01	£26,604.48
Metasequoia glyptostroboides	7	3.72	0.06	2.27	<0.01	£25,197.30
Cupressocyparis leylandii	85	4.77	0.17	9.72	0.01	£25,156.23
Malus tschonoskii	71	6.64	0.31	6.82	0.01	£24,973.77
Liriodendron tulipifera	73	4.76	0.17	6.17	<0.01	£24,187.56
Betula	140	6.35	0.40	8.32	0.01	£24,139.21
Pinus sylvestris	29	2.44	0.06	2.88	<0.01	£22,944.40
Eucalyptus	25	8.25	0.18	4.12	<0.01	£22,088.66
Alnus incana	43	5.19	0.21	5.59	<0.01	£21,037.81
Liquidambar styraciflua	143	3.04	0.11	4.45	<0.01	£20,061.57
Prunus lusitanica	75	6.64	0.35	5.40	<0.01	£19,356.23
Populus balsamifera	3	2.57	0.05	1.55	<0.01	£15,172.25
Cedrus atlantica glauca	6	1.90	0.03	2.99	<0.01	£14,944.29
Magnolia	67	3.01	0.16	3.64	<0.01	£13,944.78
Acer rubrum	28	3.47	0.12	3.33	<0.01	£13,616.57
Pterocarya fraxinifolia	7	3.79	0.07	1.88	<0.01	£13,224.52

Species	Trees	Carbon Storage (Tonnes)	Gross Carbon Seq (Tonnes/ Yr)	Avoided Runoff (m³/Yr)	Pollution Removal (Tonne/ Yr)	Replacement Cost (£)
Corylus avellana	95	2.64	0.17	7.67	0.01	£12,976.66
Salix	3	3.25	0.05	0.53	<0.01	£12,421.35
Juglans nigra	6	4.04	0.05	1.48	<0.01	£12,167.75
Morus nigra	12	3.10	0.08	1.01	<0.01	£12,084.24
Laburnum anagyroides	57	3.82	0.17	9.98	0.01	£10,812.00
Alnus rubra	14	2.62	0.09	1.84	<0.01	£10,789.65
Chamaecyparis	45	1.88	0.07	2.43	<0.01	£10,680.78
Parrotia persica	36	2.17	0.09	3.60	<0.01	£10,458.10
Cotoneaster frigidus	49	3.65	0.17	3.46	<0.01	£10,393.53
Ligustrum lucidum	51	3.25	0.17	2.61	<0.01	£9,534.36
Crataegus x lavallei	44	2.58	0.14	3.34	<0.01	£9,194.67
Ulmus glabra	43	3.92	0.15	5.17	<0.01	£8,701.61
Taxodium distichum	8	1.26	0.03	1.67	<0.01	£8,646.90
Ficus carica	29	1.81	0.08	2.13	<0.01	£8,342.83
Crataegus crus-galli	29	1.98	0.10	1.71	<0.01	£8,096.53
Syringa vulgaris	53	1.98	0.12	2.84	<0.01	£8,044.53
Photinia x fraseri	105	0.87	0.11	1.18	<0.01	£7,944.79
Eucalyptus gunnii	20	2.68	0.08	1.44	<0.01	£7,776.98
Prunus domestica	47	3.27	0.17	2.86	<0.01	£7,690.55
Prunus sargentii	43	1.98	0.11	2.23	<0.01	£7,150.14
Salix matsudana	7	1.73	0.05	1.39	<0.01	£7,113.96
Cupressus	47	1.21	0.05	2.31	<0.01	£6,804.20
Prunus serrula	55	2.11	0.15	2.17	<0.01	£6,705.02
Ulmus carpinifolia 'Hollandica'	15	2.45	0.08	2.34	<0.01	£5,876.44
Nothofagus obliqua	4	1.92	0.05	1.69	<0.01	£5,845.45
Ostrya carpinifolia	18	1.11	0.04	1.29	<0.01	£5,640.95
Cedrus deodara	5	0.61	0.02	1.13	<0.01	£5,506.52
Magnolia kobus	6	1.16	0.03	0.77	<0.01	£5,184.13
Picea abies	11	1.34	0.04	2.17	<0.01	£5,154.75
Ulmus procera	29	2.51	0.10	3.59	<0.01	£5,070.13
Cupressus macrocarpa	12	0.91	0.03	0.54	<0.01	£4,928.64
Amelanchier arborea	58	0.25	0.04	0.65	<0.01	£4,911.39

Species	Trees	Carbon Storage (Tonnes)	Gross Carbon Seq (Tonnes/ Yr)	Avoided Runoff (m^3/Yr)	Pollution Removal (Tonne/ Yr)	Replacement Cost (£)
Cotoneaster	50	1.56	0.11	3.69	<0.01	£4,830.81
Quercus petraea	3	1.17	0.03	0.50	<0.01	£4,763.49
Crataegus prunifolia	20	1.02	0.05	0.81	<0.01	£4,372.68
Tilia cordata 'greenspire'	5	0.65	0.02	0.82	<0.01	£4,226.84
Betula utilis	49	0.14	0.03	0.41	<0.01	£4,226.25
Alnus viridis	4	0.92	0.03	0.73	<0.01	£4,014.30
Tilia americana	4	0.54	0.01	0.76	<0.01	£3,945.53
Acer platanoides 'Schwedleri'	4	0.99	0.03	0.97	<0.01	£3,923.11
Prunus dulcis	32	1.28	0.07	1.82	<0.01	£3,919.38
Crataegus laevigata	35	0.79	0.06	1.16	<0.01	£3,745.77
Acer palmatum	11	0.67	0.02	1.18	<0.01	£3,694.32
Sequoiadendron giganteum	1	0.50	0.01	0.26	<0.01	£3,473.25
Malus sylvestris	13	0.77	0.04	0.68	<0.01	£3,422.43
Eriobotrya japonica	24	1.02	0.06	1.52	<0.01	£3,348.60
Acer griseum	15	0.64	0.03	0.67	<0.01	£3,246.49
Cedrus atlantica	3	0.38	0.01	0.71	<0.01	£3,242.88
Betula ermanii	19	0.89	0.05	1.03	<0.01	£3,208.37
Acer saccharum	3	0.92	0.03	0.83	<0.01	£3,083.80
Cercis siliquastrum	9	0.76	0.03	0.68	<0.01	£3,082.93
Amelanchier alnifolia	35	0.07	0.02	0.15	<0.01	£3,018.75
Sorbus sargentiana	18	0.85	0.05	0.98	<0.01	£2,998.32
Sorbus hupehensis	26	0.58	0.04	0.64	<0.01	£2,972.14
Ilex	12	0.78	0.04	0.63	<0.01	£2,949.91
Fraxinus americana	4	0.80	0.02	0.71	<0.01	£2,916.71
Ligustrum ovalifolium	14	0.93	0.05	0.87	<0.01	£2,711.72
Pyrus salicifolia	14	0.69	0.04	0.30	<0.01	£2,558.02
Salix x chrysocoma	3	0.61	0.02	0.56	<0.01	£2,500.92
Betula nigra	18	0.42	0.03	0.45	<0.01	£2,194.81
Acacia dealbata	6	0.57	0.02	0.72	<0.01	£2,158.19
Quercus robur 'fastigiata'	15	0.38	0.02	0.26	<0.01	£2,124.60
Arbutus unedo	6	0.41	0.02	0.35	<0.01	£2,081.74
Pinus radiata	1	0.21	<0.01	0.26	<0.01	£2,070.97

Species	Trees	Carbon Storage (Tonnes)	Gross Carbon Seq (Tonnes/ Yr)	Avoided Runoff (m³/Yr)	Pollution Removal (Tonne/ Yr)	Replacement Cost (£)
Quercus palustris	16	0.23	0.02	0.27	<0.01	£2,060.92
Laburnum x watereri	8	0.66	0.03	0.28	<0.01	£1,965.30
Betula albo-sinensis	19	0.24	0.02	0.42	<0.01	£1,961.18
Tamarix tetragyna	22	0.33	0.03	0.68	<0.01	£1,912.83
Prunus fruticosa	25	0.50	0.05	0.33	<0.01	£1,905.17
Quercus coccinea	5	0.46	0.02	0.65	<0.01	£1,873.75
Pinus	1	0.20	0.01	0.35	<0.01	£1,871.88
Sophora japonica	13	0.61	0.04	0.49	<0.01	£1,870.31
Koelreuteria paniculata	24	0.14	0.02	0.37	<0.01	£1,853.33
Zelkova serrata	19	0.15	0.02	0.39	<0.01	£1,821.96
Ulmus	40	0.62	0.05	1.30	<0.01	£1,743.76
Acer davidii	13	0.33	0.02	0.57	<0.01	£1,646.76
Yucca	4	0.02	<0.01	0.19	<0.01	£1,615.34
Catalpa speciosa	1	0.42	0.01	0.27	<0.01	£1,579.03
Fraxinus angustifolia	1	0.24	0.01	0.18	<0.01	£1,560.73
Pittosporum tenuifolium	5	0.44	0.02	0.30	<0.01	£1,549.47
Rhus	19	0.34	0.03	0.99	<0.01	£1,540.46
Ulmus x hollandica	3	0.67	0.02	0.71	<0.01	£1,510.07
Aesculus indica	5	0.26	0.01	0.50	<0.01	£1,303.11
Amelanchier canadensis	13	0.30	0.03	0.36	<0.01	£1,287.07
Malus floribunda	13	0.24	0.02	0.40	<0.01	£1,194.98
Cordyline australis	4	0.01	<0.01	0.14	<0.01	£1,193.80
Taxus	11	0.12	0.01	0.87	<0.01	£1,097.01
Sorbus torminalis	11	0.18	0.02	0.31	<0.01	£1,050.27
Olea europaea	13	0.22	0.02	0.44	<0.01	£1,039.30
Thuja plicata	9	0.07	<0.01	0.36	<0.01	£968.40
Cercidiphyllum japonicum	3	0.19	0.01	0.34	<0.01	£923.22
Juniperus	7	0.20	0.01	0.36	<0.01	£876.53
Acer ginnala	3	0.18	0.01	0.22	<0.01	£839.21
Lagerstroemia indica	10	0.14	0.01	0.19	<0.01	£819.67
Amelanchier laevis	8	0.17	0.01	0.39	<0.01	£802.66
Cornus	14	0.12	0.01	0.49	<0.01	£778.39

Species	Trees	Carbon Storage (Tonnes)	Gross Carbon Seq (Tonnes/ Yr)	Avoided Runoff (m³/Yr)	Pollution Removal (Tonne/ Yr)	Replacement Cost (£)
Clerodendrum trichotomum	10	0.02	<0.01	0.11	<0.01	£760.75
Acer japonicum	3	0.15	0.01	0.26	<0.01	£724.92
Cornus mas	9	0.27	0.02	0.71	<0.01	£628.79
Cercis canadensis	8	0.01	<0.01	0.06	<0.01	£608.60
Euonymus europaea	8	0.01	<0.01	0.06	<0.01	£608.60
Hamamelis	8	0.01	<0.01	0.03	<0.01	£608.60
Nothofagus antarctica	5	0.11	0.01	0.14	<0.01	£576.03
Prunus spinosa	7	0.08	0.01	0.15	<0.01	£575.64
Sorbus commixta	5	0.02	<0.01	0.05	<0.01	£431.25
Rhamnus cathartica	1	0.11	<0.01	0.02	<0.01	£403.42
Pinus wallichiana	4	0.03	<0.01	0.06	<0.01	£387.09
Hibiscus	5	0.01	<0.01	0.03	<0.01	£380.38
Paulownia tomentosa	5	0.02	<0.01	0.06	<0.01	£372.11
Zelkova carpinifolia	1	0.11	<0.01	0.06	<0.01	£352.84
Acer rubrum 'armstrong'	4	0.01	<0.01	0.04	<0.01	£335.62
Trachycarpus fortunei	1	<0.01	<0.01	0.05	<0.01	£333.46
Sorbus vilmorinii	2	0.11	0.01	0.07	<0.01	£307.87
Picea	3	0.11	0.01	0.20	<0.01	£296.92
Davidia involucrata	4	0.02	<0.01	0.14	<0.01	£287.76
Aesculus flava	4	0.01	<0.01	0.10	<0.01	£286.35
Acer x freemanii	3	0.07	0.01	0.10	<0.01	£285.30
Abies	4	0.04	<0.01	0.11	<0.01	£255.48
Quercus	3	0.01	<0.01	0.01	<0.01	£249.38
Viburnum tinus	3	0.03	<0.01	0.05	<0.01	£249.37
Ligustrum vulgare	3	0.11	0.01	0.32	<0.01	£238.89
Nyssa sylvatica	3	0.02	<0.01	0.07	<0.01	£228.22
Prunus maackii	3	0.06	0.01	0.12	<0.01	£219.65
Quercus hispanica	1	0.08	<0.01	0.10	<0.01	£200.53
Sorbus americana	2	0.06	<0.01	0.08	<0.01	£191.27
Mespilus germanica	3	0.06	0.01	0.09	<0.01	£188.30
Araucaria araucana	2	0.02	<0.01	0.06	<0.01	£177.41
Magnolia grandiflora	2	0.01	<0.01	0.02	<0.01	£172.50

Species	Trees	Carbon Storage (Tonnes)	Gross Carbon Seq (Tonnes/ Yr)	Avoided Runoff (m^3/Yr)	Pollution Removal (Tonne/ Yr)	Replacement Cost (£)
Cornus kousa	3	<0.01	<0.01	0.01	<0.01	£170.77
Betula maximowicziana	2	<0.01	<0.01	0.01	<0.01	£163.13
Carya illinoinensis	2	<0.01	<0.01	0.02	<0.01	£152.15
Celtis occidentalis	2	<0.01	<0.01	0.02	<0.01	£152.15
Eucommia ulmoides	2	<0.01	<0.01	0.03	<0.01	£152.15
Tetradium daniellii	2	<0.01	<0.01	0.02	<0.01	£152.15
Magnolia wilsonii	1	0.05	<0.01	0.09	<0.01	£144.88
Morus alba	2	0.02	<0.01	0.06	<0.01	£143.88
Larix decidua	5	<0.01	<0.01	0.03	<0.01	£142.31
Buddleja davidii	2	0.02	<0.01	0.05	<0.01	£135.61
Cornus florida	1	0.07	<0.01	0.09	<0.01	£117.96
Liquidambar	2	0.01	<0.01	0.03	<0.01	£113.85
Juniperus communis	2	0.01	<0.01	0.03	<0.01	£107.66
Griselinia littoralis	2	0.03	<0.01	0.10	<0.01	£101.48
Juniperus chinensis	2	0.01	<0.01	0.01	<0.01	£101.48
Pseudotsuga menziesii	1	0.02	<0.01	0.18	<0.01	£89.29
Acer rubrum 'red sunset'	1	<0.01	<0.01	0.01	<0.01	£86.25
Alnus	1	<0.01	<0.01	0.01	<0.01	£86.25
Carpinus japonica	1	<0.01	<0.01	0.01	<0.01	£86.25
Quercus castaneifolia	1	<0.01	<0.01	<0.01	<0.01	£86.25
Pinus strobus	1	0.01	<0.01	0.02	<0.01	£76.88
Broussonetia papyrifera	1	<0.01	<0.01	0.01	<0.01	£76.08
Cladrastis kentukea	1	<0.01	<0.01	0.01	<0.01	£76.08
Fremontodendron californicum	1	<0.01	<0.01	0.01	<0.01	£76.08
Gymnocladus dioicus	1	<0.01	<0.01	0.02	<0.01	£76.08
Liriodendron tulipifera Fastigiatum	1	<0.01	<0.01	0.01	<0.01	£76.08
Pseudopanax	1	0.01	<0.01	0.02	<0.01	£67.81
Rhododendron	1	<0.01	<0.01	0.02	<0.01	£67.81
Sequoia sempervirens	1	<0.01	<0.01	0.02	<0.01	£67.33
Casuarina equisetifolia	1	0.01	<0.01	0.03	<0.01	£60.01
Cryptomeria japonica	1	0.02	<0.01	0.07	<0.01	£60.01

Species	Trees	Carbon Storage (Tonnes)	Gross Carbon Seq (Tonnes/ Yr)	Avoided Runoff (m^3/Yr)	Pollution Removal (Tonne/ Yr)	Replacement Cost (£)
Picea pungens	1	0.01	<0.01	0.03	<0.01	£59.45
Abies alba	1	<0.01	<0.01	0.02	<0.01	£56.93
Chamaecyparis nootkatensis	1	<0.01	<0.01	0.03	<0.01	£56.93
Abies concolor	1	0.01	<0.01	0.03	<0.01	£50.74
Elaeagnus angustifolia	1	0.01	<0.01	0.01	<0.01	£50.74
Total	25,890	691,302.73	13,200.71	10,218.62	175,446.86	£19,725,301.40

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, sulphur 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 Asian Longhorned beetle, emerald ash borer, gypsy moth, and Dutch elm disease.

To calculate current carbon storage, biomass for each tree was calculated using equations from the literature and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations[17]. To adjust for this difference, biomass results for open-grown urban trees were multiplied by 0.8. No adjustment was made for trees found in natural stand conditions. Tree dry-weight biomass was converted to stored carbon by multiplying by 0.5.

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

The amount of oxygen produced is estimated from carbon sequestration based on atomic weights: net 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[18].

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 sulphur and nitrogen dioxides based on a hybrid of big-leaf and multi-layer canopy deposition models[19]. 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

[17] Nowak 1994

[18] Nowak, David J., Hoehn, R., and Crane, D. 2007.

[19] Baldocchi 1987, 1988

based on average measured values from the literature[20] [21] that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere[22].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[23] [24].

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

[20] Bidwell and Fraser 1972

[21] Lovett 1994

[22] Zinke 1967

[23] Hollis, 2007

[24] Rogers et al (2012)

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