Forest Research

i-Tree Eco valuation of Public Trees in Bicester: a Provisional Analysis

February 2018

The Research Agency of the
Forestry Commission

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Citation

This report should be cited as:

Vaz Monteiro, M., Handley, P., Doick, K.J., Smith, A. (2018). i-Tree Eco valuation of public trees in Bicester: a provisional analysis. Forest Research, Farnham. 38pp.

Acknowledgements

This report is an output of project 'Tools for Urban Planning and Evaluating Urban Green Infrastructure: Bicester and Beyond' funded by the Natural Environment Research Council's (NERC) 2015 Green Infrastructure Innovation Projects Call (Award number: NE/N017730/1).

Contents

Summary

Urban trees provide a range of services, often termed ecosystem services, that help alleviate problems associated with the high population densities found in urban areas. For example, urban trees improve local air quality, capture carbon, reduce flooding and cool urban environments. They provide food and habitat for animals, such as birds and bees, and can improve social cohesion in communities. All the trees in the urban realm – in public and private spaces, along linear routes and waterways and in amenity areas – are collectively known as the 'urban forest'. Urban forests are, therefore, a valuable source of ecosystem services in towns and cities.

Planning developments often overlook the value of urban trees, quantifiable or otherwise. Valuing the quantifiable services provided by public trees in Bicester could improve this and allow Bicester Town Council to increase the profile of the urban forest they manage. Valuing ecosystem services also aids town planners, landscape architects and tree officers to plan where trees can be planted for maximum benefit.

i-Tree is a state-of-the-art, peer-reviewed software suite from the USDA Forest Service that provides urban and community forestry analysis and benefits assessment tools. An i-Tree Eco analysis was run for a tree database covering all trees in public space under the responsibility of the council. This database was created from GIS shapefiles given that there was no access to a full inventory of the public trees in Bicester (see Appendix I).

The information given in this short report is only an indication of what i-Tree Eco could demonstrate if such an inventory was assessed; it should not be seen as an accurate estimation of the structure and value of Bicester public trees.

For further details on how to conduct a full i-Tree Eco study contact the authors or visit www.itreetools.org or www.forestry.gov.uk/fr/itree.

Key results for this analysis

- Number of suitable trees in the database: 16,275
- Most common species of trees: field maple, common ash and crack willow
- Percentage of trees with less than 20 cm diameter: 83.4%
- Replacement Cost valued at £5.41 million
- Avoided runoff of 2,330 m^3/year (estimated value of £3,500/year)
- Pollution removal of 2 tonnes/year (estimated value of £11,500/year)
- Carbon storage of 1,270 tonnes (estimated value of £295,000)
- Carbon gross sequestration of 53 tonnes/year (valued at ca. £12,400/year)
- Additional benefits (not valued) will include visual amenity, cultural value, shading /cooling by transpiration and biodiversity value.

Introduction

Urban trees provide a range of services that benefit humans, named "ecosystem services". Trees improve health by improving local air and water quality by absorbing and filtering pollutants (Bolund and Hunhammar, 1999). Trees also reduce the urban heat island effect (Akbari et al., 2001), decreasing illnesses associated with heat. There is evidence that urban greenery can help at the same time reduce stress levels and improve recovery time from illness (Ulrich, 1979).

In addition, urban trees provide economic benefits. They store carbon, absorbing it into their tissues, helping to offset carbon emissions produced by other urban activities (Nowak et al., 2008). Urban trees further alleviate flash flooding, a problem that costs cities millions of pounds each year (Bolund and Hunhammar, 1999). Commercial and private property value is also increased with the addition of trees (Forestry Commission, 2010).

Trees provide valuable habitat for much of the UK's urban wildlife too, including bats (Entwistle et al., 2001) and bees (RHS, 2017a). They provide local residents with a focal point to improve social cohesion and aid education with regards to environmental issues (Trees for Cities, 2015).

Raising awareness of the benefits that urban trees provide to society can help support the case for their improved management, establish a baseline against which to monitor changes and set targets for future tree cover. It can also be used to understand the economic benefits of these trees in relation to the costs to conserve them.

A range of the ecosystem services provided by urban trees are quantifiable using models such as i-Tree Eco, developed by the US Forest Service and associates (Davey Tree Expert Company, National Arbor Day Foundation, Society of Municipal Arborists, International Society of Arboriculture and Casey Trees) to aid in planning tree planting. i-Tree Eco is currently the most complete method available to value a whole suite of urban forest ecosystem services (Sarajevs, 2011), including pollutant interception, alleviation of water runoff and carbon uptake. i-Tree Eco has been used successfully in over 60 cities globally, including over twenty cities in the UK.

In this report we present the findings of an i-Tree Eco analysis of trees in public space under the responsibility of Bicester town council. This database was created from GIS shapefiles given that there was no access to a full inventory of the public trees in Bicester (see Methodology and Appendix I). Therefore, the information given in this short report is only an indication of what i-Tree Eco could demonstrate if such an inventory was assessed and it should not be seen as an accurate estimation of the structure and value of Bicester public trees.

Methodology

The database used for this analysis was created for the Bicester and Beyond project from two GIS shapefiles that included:

- individual trees represented by circles with three attributes: species, common name and 'trunk' size (diameter at breast height (DBH) in cm).
- tree groups with the same three attributes; in this case it was assumed that 'trunk' corresponded to the average DBH for trees in the group.

The database included only trees in the public domain that are the responsibility of the Town Council, i.e. it excluded trees in private gardens or on commercial premises or school sites.

The raw dataset provided by Cherwell District Council featured a number of quality problems. The Bicester and Beyond project team performed some preliminary quality assurance and 'cleaning' before giving the dataset to the Urban Forest Research Group for analysis, although it was not possible to resolve all issues (e.g. large numbers of trees with zero DBH, blank species, and overlapping polygons). Before inserting trees into the model, the total number of trees within the database was found assuming that each tree group polygon represented multiple trees with an average DBH. The crown width of each individual tree present in the tree group was found based on coefficients given by Vaz Monteiro et al. (2016), allowing quantification of canopy area for each tree. Appendix I presents detailed information on how data were prepared before entry in i-Tree Eco.

The National Tree Map predicts 112.2 ha of trees for Bicester. The dataset shared accounted in total for 27.8 ha of trees (11.7 ha of tree groups and 16.1 ha of individual trees), so 24.7% of the National Tree Map. This is probably mainly because the tree database includes only Town Council trees (see above), though it may also reflect possible errors in the database (e.g. a large number of trees with 'zero' DBH were excluded). The estimated values therefore reflect only a fraction of the value of all the trees in Bicester.

This is a short report illustrating the potential of running an i-Tree Eco model for the urban forest of Bicester. For examples of full reports for other UK cities see https://www.forestry.gov.uk/fr/itree.

Running the analysis in i-Tree Eco

Analysis was conducted in i-Tree Eco using a full inventory mode (see Appendix I for details). i-Tree was designed in and for the US. Ecosystem services valuations were, therefore, anglicised using ecosystem services valuation methods outlined by the UK Treasury and details of how this was carried out are within the results of each section.

Weather data used was for the year 2013, recorded at Brize Norton weather station (51.75° N, 1.58° W) located close to Bicester and pollution data for the region was obtained from https://ww.uk-air.defra.gov.uk as integrated within i-Tree Eco version 6.

Table 1. Outputs calculated by i-Tree.

Urban forest structure and composition	Species composition, DBH class Total leaf area and % leaf area by species Importance value
Ecosystem services	Avoided surface water runoff Air pollution removal for CO, NO_2, SO_2, O_3 and $PM_{2.5}$ % of total air pollution removed by trees Current carbon storage Carbon sequestered
Replacement costs and functional values	Replacement cost based upon structural value in £ (CTLA) Avoided surface water runoff/sewerage charges in £[a] Carbon storage and sequestration value in £[b] Pollution removal value in £[c]

[a] The value of avoided runoff is calculated based on local values of standard rate charged for sewerage, in this case £1.516 per m^3.

[b] Based on the United States externality cost prices (USEC) and the United Kingdom social damage costs (UKSDC) where available (per metric ton). Individual values used are presented in the Air Pollution Removal section.

[c] The baseline year of 2016 and the respective 2016 DECC value of £63 per metric ton.

Results

Given the nature of the data, the information in this report does not represent a robust interpretation of the structure and value of the public trees in Bicester. This report only exemplifies what could be achieved if a full tree inventory of public trees was available for Bicester, or if a sample-plot based approach was adopted in data gathering, and analysed in i-Tree Eco.

Urban Forest Structure

55% of trees in the database were denoted as 'species- unknown'; consequently, these were attributed to the genus *Fraxinus* (ash) to enable processing in i-Tree Eco (see Appendix I). These trees were not considered in the list of 10 most common species. **For the remaining trees (45% of trees in the database), the most common were field maple, common ash and crack willow.**

The ten most common tree species accounted for 54% of all trees of a known category and the breakdown of species over this percentage is represented in Figure 1.

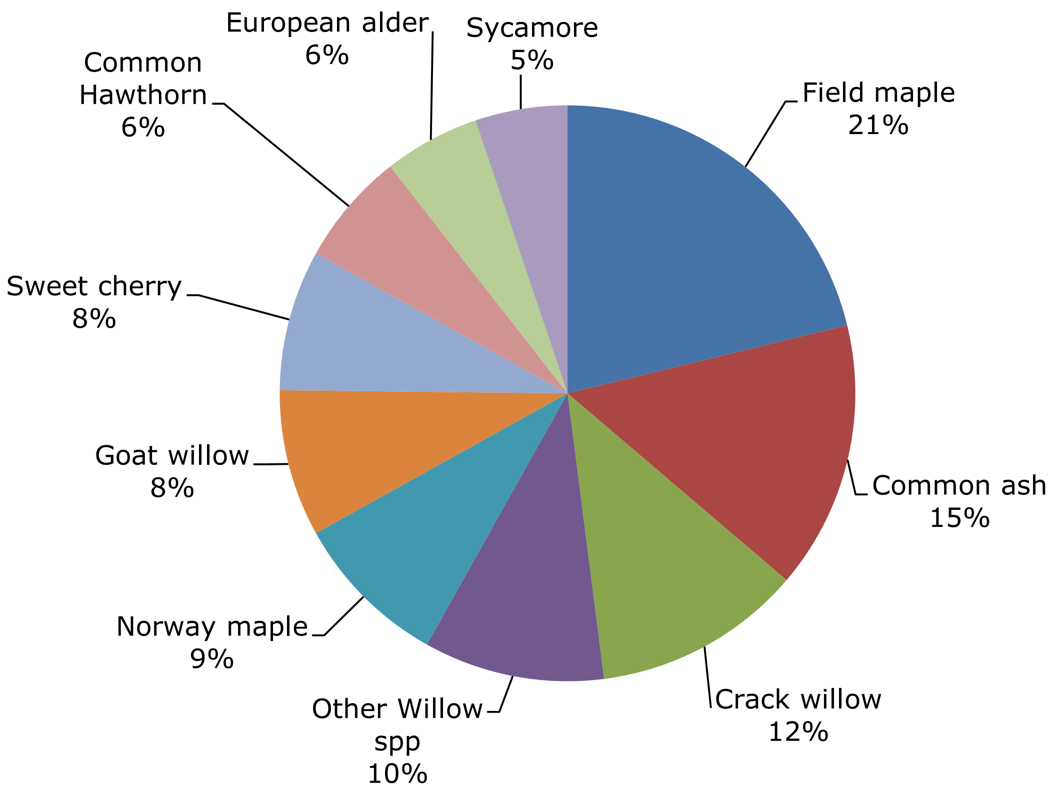


Figure 1. Breakdown of the most 10 common tree species. Original common names have been changed where needed so that they could be recognised within i-Tree.

The origin of tree species impacts their ability to resist pests and diseases. New pests and diseases, such as Chalara ash dieback, are emerging (Forestry Commission, 2014). Additionally, stresses such as prolonged exposure to drought could increase due to climate change (Murphy et al., 2009). These factors are leading councils to consider the use of exotic species. Exotic species tend to have fewer pests associated with them due to being removed from the home range of their specialist herbivores and diseases (Connor et al., 1980). Trees from warmer climates may also be able to withstand the effects of climate change better (RHS, 2017b). However, there is an ongoing debate about whether these benefits outweigh the costs of planting exotics (Johnston et al., 2011). Exotic species can disrupt native ecosystems by changing the available niches for wildlife to fill (Townsend et al., 2008). They also support fewer native animals (Kennedy and Southwood, 1984) and can become invasive due to their lower association with pests (Mitchell and Power, 2003). Thus, a balance of native and non-native species may provide the most resilient solution. Within the 10 most common species, the large majority of trees were native (>75%).

The size distribution of trees is also important for a resilient population. Large, mature trees offer unique ecological roles not offered by small, younger trees (Lindenmayer et al., 2012). 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.

In the database, trees with DBH less than 20 cm constituted 83.4% of trees (Figure 2). The number of trees in each DBH class then declines successively, where trees with DBH's higher than 60 cm make up for 1.3%. These values are very different from the ideal values suggested for street trees in America to ensure healthy urban tree stocks, as shown by the diamonds on Figure 2 (Richards, 1983). A tendency for a prevalence of trees with small DBHs has been also identified across other English towns and cities, although not to the same extent (trees with DBH less than 20 cm ranged from 45% to 67% in the i-tree Eco evaluations of Burton-upon-Trent, London, Oldham, Petersfield, Southampton and Torbay). The data quality issues linked to the dataset used may have led to an underestimation of the DBH of various trees. However, it is also possible that the average DBH is genuinely low in Bicester.

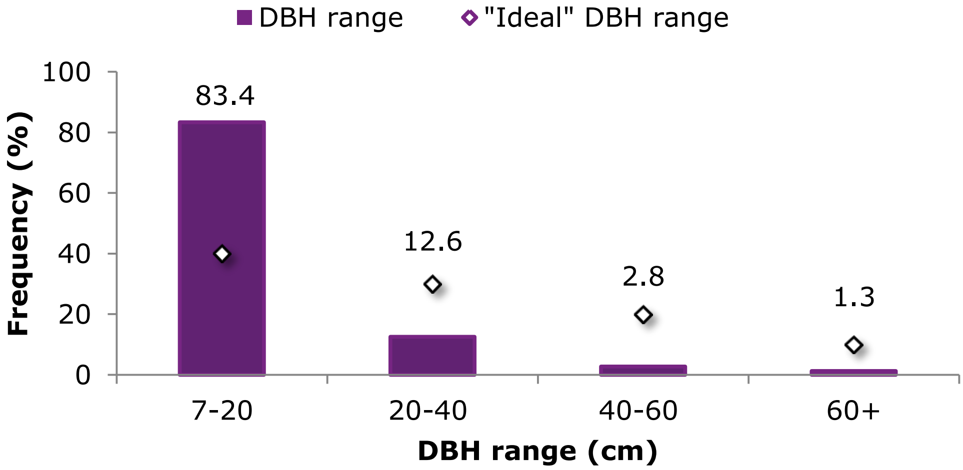


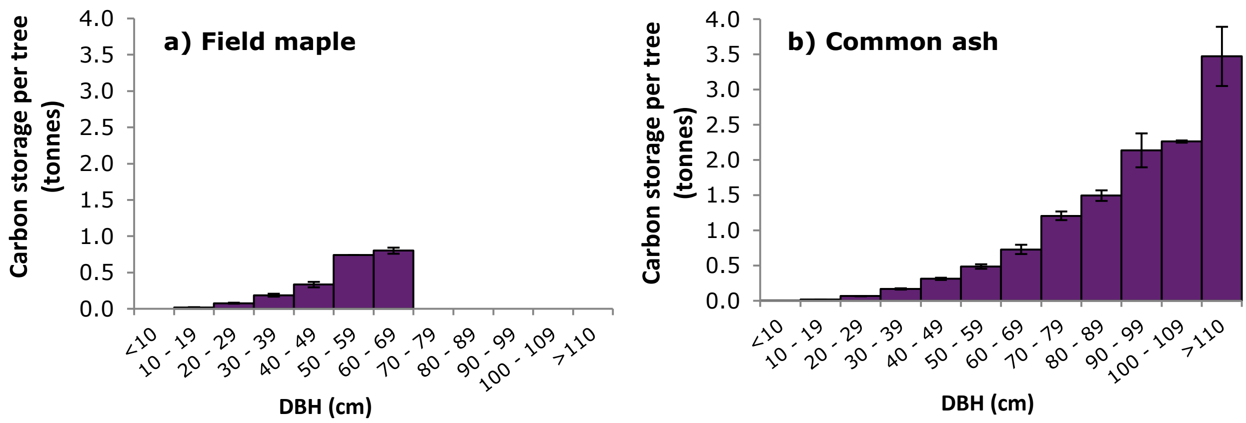
Figure 2. DBH ranges of trees encountered in the database. Diamonds represent recommended frequencies for that DBH class (40, 30, 20, 10%) as outlined by Richards (1983).

The group of trees in the lower DBH classes (7-20 cm and 20-40 cm) is composed of small stature trees and young large stature trees. There is evidence to suggest that large trees provide more ecosystem services than small stature ones (see box 1) and provide more benefits compared to their costs (Center for Urban Forest Research, 2006; Sunderland et al., 2012). However, little work has been conducted to compare large trees with dense stands of small stature trees such as those produced by field maple and hawthorn, so a comparison is difficult. Regardless of that, to ensure future resilience within Bicester's urban forest, young large stature trees should be allowed to reach their potential size.

Box 1. Ecosystem services delivered by trees of different statures

Forthcoming Forestry Commission Research Reports examine the delivery of ecosystem services modelled by i-Tree Eco changes a tree's lifetime and between trees of different stature (Hand et al., 2018a, 2018b). They show that large stature trees provide greater quantities of beneficial than medium or small stature trees.

The graphs below, adapted from the reports, show the mass of predicted carbon stored by trees with different DBHs for a) field maple (a small to medium stature tree) and b) common ash (a large stature tree). These species are some of the most common in Bicester.



Bars are shown with ±2 standard error of the mean.

While only carbon is featured here, four ecosystem services are modelled and presented in the forthcoming Research Reports.

Leaf Area

The healthy leaf surface area of trees is an indicator of many of the benefits trees can provide. The removal of pollutants from the atmosphere, for example, relies on leaf surface area (Nowak et al., 2006), as do other factors such as shading ability.

i-Tree estimates that Bicester's public trees provide 153.1 ha of leaf area. Taking leaf area and prevalence into account, it is possible to rank tree species by calculating an 'importance value'. High importance values are associated with species that currently dominate the urban forest structure.

The three most important species (after excluding those included in the *Fraxinus* category) were a mix of trees with dense, small leaves, such as crack willow, and trees with large leaves, such as Norway maple. The most prevalent species (Figure 1) were not always the most important (Table 2).

Table 2. Percentage of leaf area across the entire dataset and importance value of the 10 most important species (trees denoted in the data as species- unknown not included).

Species	Leaf Area (%)	Importance Value
Field maple	7.5	12.6
Common ash	6.5	10.1
Norway maple	6.8	9.0
Crack willow	3.5	6.4
Sycamore	4.2	5.5
willow spp	2.8	5.3
Sweet cherry	2.8	4.7
European alder	2.3	3.6
Goat willow	1.1	3.1
Silver lime	2.1	3.0

Replacement Cost

According to CTLA valuation (Appendix I), which does not take into account the health or amenity value of trees, **Bicester's public trees are worth £5.41 million**. This is the cost of replacing those trees with a similar one should it be lost.

Avoided surface water runoff

The infrastructure required to remove surface water from towns and cities is costly and in the UK in particular can be outdated. This means that in large storm events or failed water pipes, surface water may not be removed quickly and damage to property can incur.

Trees can ameliorate this problem by intercepting rainwater, retaining it on their leaves and absorbing some into their tissues for use in respiration. **The public trees in Bicester intercept an estimated 2,330 m^3 of water per year, worth £3,530 in sewerage charges.** Avoided runoff is estimated based on local weather; in this region, the total annual precipitation in 2013 was 29.1 cm.

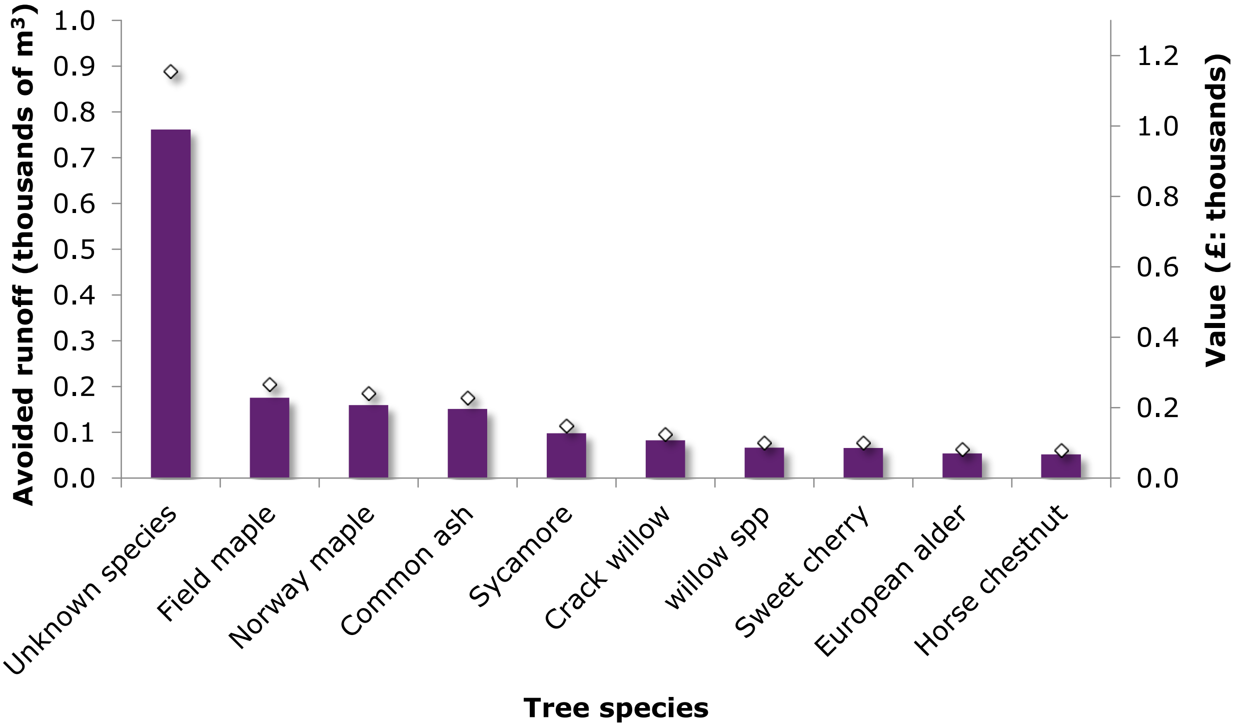


Figure 3. Avoided water runoff (columns) and associated value (diamonds) for the species with greatest attenuation capacity. The category 'unknown species' classifies all those that could not be matched to a certain species or genus.

Air Pollution Removal

Air pollution leads to a decline in human health, a reduction in the quality of ecosystems and it can damage buildings through the formation of acid rain (Table 3).

Trees and shrubs can mitigate the impacts of air pollution by directly reducing airborne pollutants as well as reducing local temperatures. Trees can absorb pollutants through their stomata, or simply intercept pollutants that are retained on the plant surface (Nowak et al., 2006). This leads to year-long benefits, with bark continuing to intercept pollutants throughout winter (Nowak et al., 2006). Plants also reduce local temperatures by providing shade and by transpiring (Bolund and Hunhammar, 1999), reducing the rate at which air pollutants are formed, particularly ozone (O_3; Jacob and Winner, 2009). However, trees can also contribute to ozone production by emitting volatile organic compounds (VOCs) that react with pollutants (Lee et al., 2006). i-Tree reports biogenic emissions of Monoterpene and Isoprene, the most important naturally emitted VOCs (Stewart et al., 2002).

Table 3. Urban pollutants, their health effects and causes (www.air-quality.org.uk).

Pollutant	Health effects	Source
NO_2	Shortness of breath Chest pains	Fossil fuel combustion, predominantly power stations (21%) and cars (44%)
O_3	Irritation to respiratory tract, particularly for asthma sufferers	From NO_2 reacting with sunlight
SO_2	Impairs lung function Forms acid rain that acidifies freshwater and damages vegetation	Fossil fuel combustion, predominantly burning coal (50%)
CO	Long term exposure is life threatening due to its affinity with haemoglobin	Carbon combustion under low oxygen conditions i.e. in petrol cars
$PM_{2.5}$	Carcinogenic Responsible for 10 000 premature deaths per year	Varied causes, cars (20%) and residential properties (20%) major contributors

According to this analysis, public trees in Bicester emitted 0.3 tonnes of volatile organic compounds (VOCs). i-Tree Eco takes the release of VOCs by trees into account to calculate the net difference in ozone production and removal.

It is estimated that 2 tonnes of airborne pollutants per year are removed by Bicester public trees, including NO_2, O_3, SO_2, CO and $PM_{2.5}$. O_3 and NO_2 were the pollutants removed in the highest volume by trees. This demonstrates that although trees can increase ozone levels by producing VOCs, they remove far more that they produce. In addition, as ozone production increases with temperature, the cooling benefits of trees reduce ozone production overall (Nowak et al., 2000).

The pollution removed from the atmosphere can be valued to aid interpretation of this data. In both the USA and the UK, pollutants are valued in terms of the damage they cause to society. However, these are valued by slightly different methods in each country, using United States Externality Costs in the US (USEC) and United Kingdom Social Damage Costs (UKSDC) in the UK. The UK method does not cover all airborne pollutants (Table 4) because of the uncertainty associated with the value of removing some airborne pollutants.

Using the US valuation system, £1,640 worth of pollutants are estimated to be removed by the public urban trees in Bicester annually (Figure 4). **Using the UK system, which only includes three pollutants, this value increases to £11,540.** The difference is mainly due to the way NO_2 removal is calculated (Table 4).

Table 4. Amount of each pollutant removed by public urban trees in Bicester and its associated value. USEC denotes United States Externality Cost and UKSDC denotes United Kingdom Social Damage Cost.

Pollutant	Amount removed (tonnes)	US value per tonnes/£	US Value (£: USEC)	UK value per tonnes/£	UK Value (£: UKSDC)
CO	0.02	984	24		
NO_2	0.84	93	78	12,205	10,237
O_3	1.16	625	724		
$PM_{2.5}$	0.04	21,778	814	33,713	1,260
SO_2	0.02	34	1	1,956	47
TOTAL	**2.08**		**1,640**		**11,544**

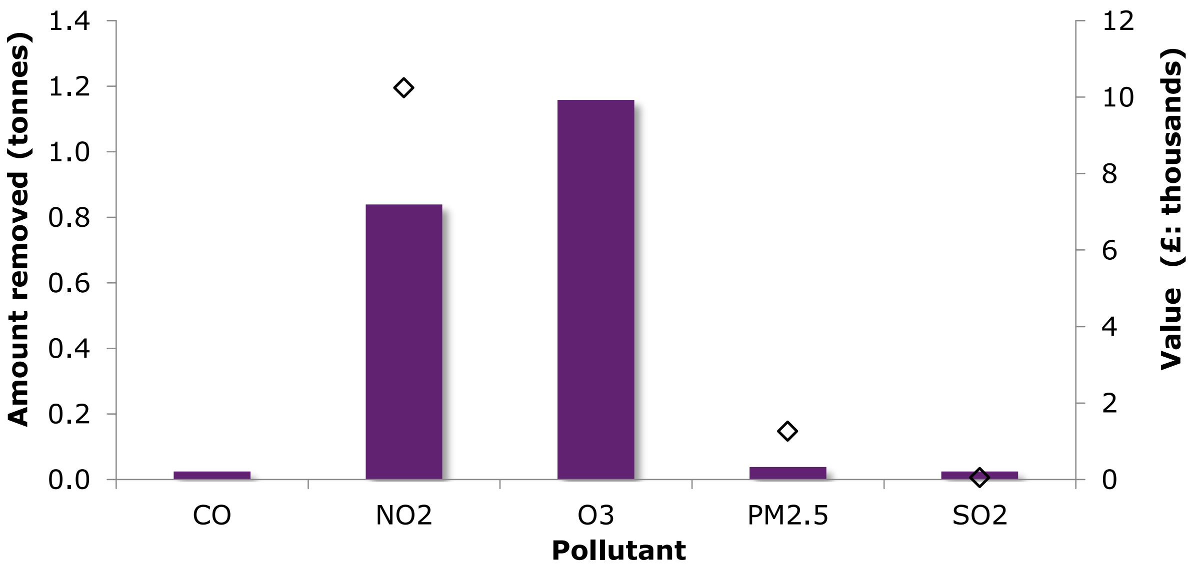


Figure 4. Mean pollutants removed by urban trees in metric tonnes (columns) and their associated value (diamonds) as valued using the UK Social Damage Cost.

The volume of airborne pollutants varied over the year, with a seasonal pattern evident in the removal of ozone, which was removed in higher volumes during spring and summer (Figure 5). This is because ozone is a product of the combination of NO_x, which was also removed in greater volumes in summer, and VOCs. The production of ozone is also more prevalent in warm temperatures (Sillman and Samson, 1995).

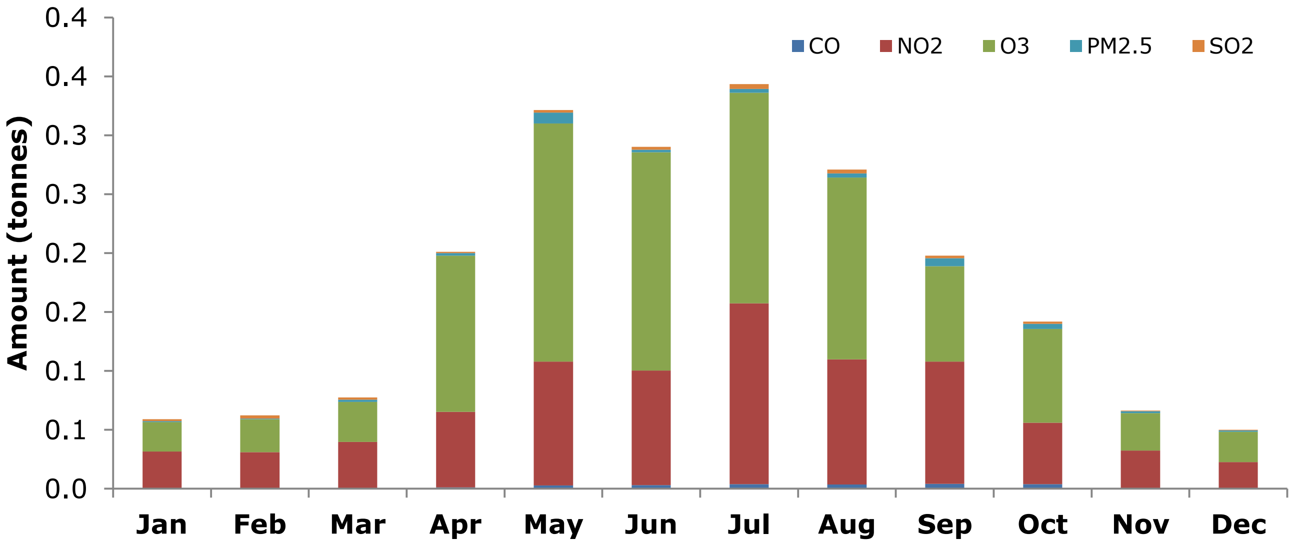


Figure 5. Monthly pollutants removed by Bicester's public trees.

Carbon Storage and Sequestration

It is estimated that Bicester's public trees store a total of 1,270 tonnes of carbon in their wood (Figure 6). Carbon storage 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. Horse chestnut, for example, makes up 1% of the tree population included in the dataset, but is responsible for 5.6% of the total carbon stored; field maple on the other hand stores 5.3% of carbon but makes up 5% of the tree population.

The carbon stored and sequestered by trees can be valued within the framework of the UK government's carbon valuation method (BEIS, 2016). 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 outside circumstances, such as fuel price.

Based on the central scenario for non-traded carbon, **it is estimated that the carbon stored in the current public tree stock is worth £295,200.** In fifty years' time (2067), this stock of carbon will be worth £888,100 (Figure 7) – this value assumes no change in the structure of the forest in terms of species assemblage, tree size or tree population size and simply reflects the increased valued of non-traded carbon year-on-year. Appendix III outlines stored carbon value from now until 2067 for the central scenario, again assuming no changes to Bicester's public trees will occur in this time.

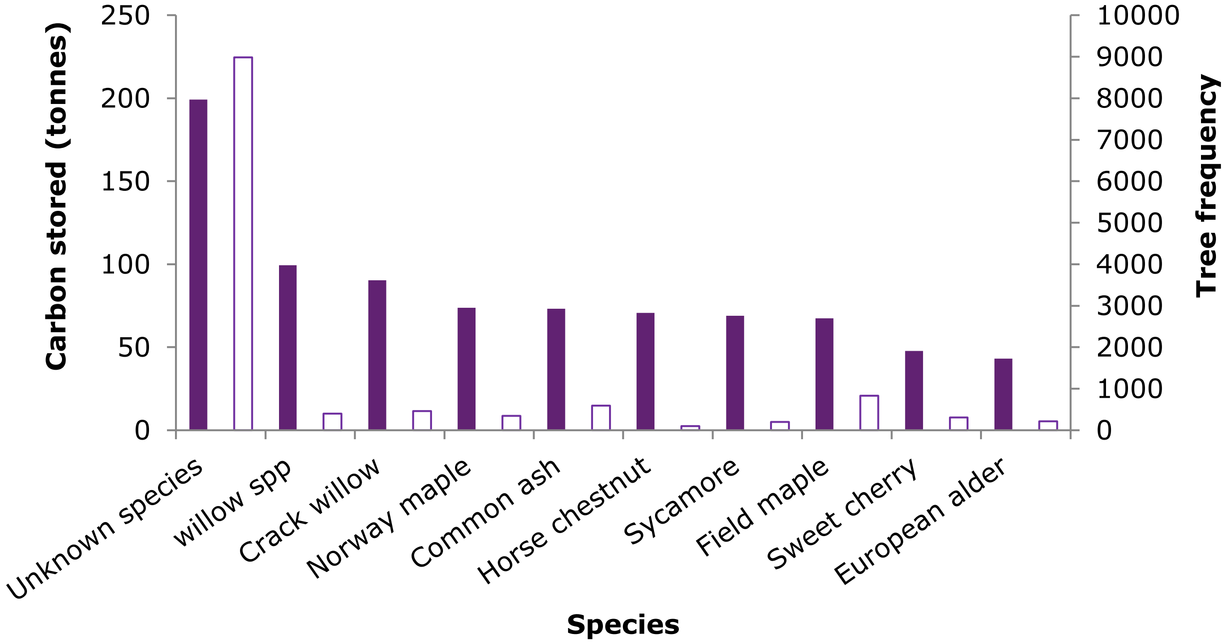


Figure 6. Amount of carbon stored in Bicester's public trees (bold bars) and the frequency of each species (blank bars) for those with greatest storage. The category 'unknown species' classifies all those that could not be matched to a certain species or genus.

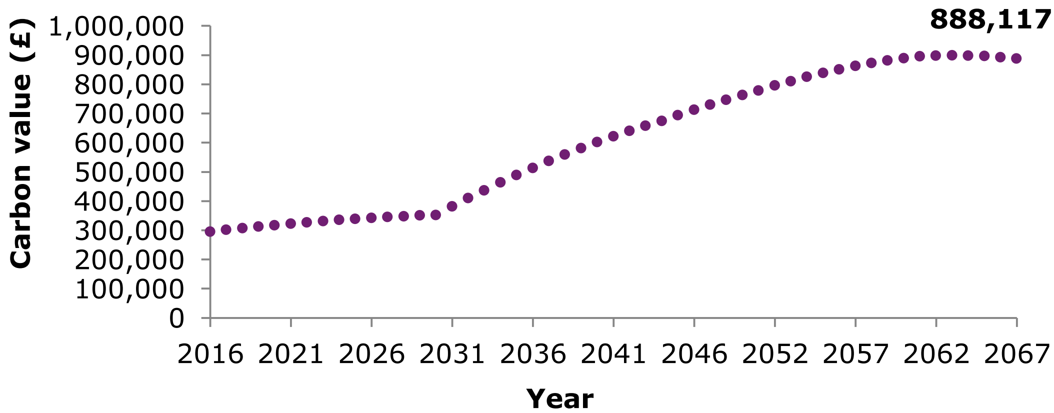


Figure 7. Value of stored carbon within Bicester's public trees during the period 2016-2067. These values are based on the UK governments non-traded carbon valuation method and assume the structure of the urban forest remains the same over time.

The gross amount of carbon sequestered by the public trees in Bicester each year is estimated at 53 tonnes (Figure 8). According to the central scenario for non-traded carbon, this is **worth approximately £12,400 per year.** This is equivalent to **the annual CO_2 emissions from 39 households or 94 cars**.

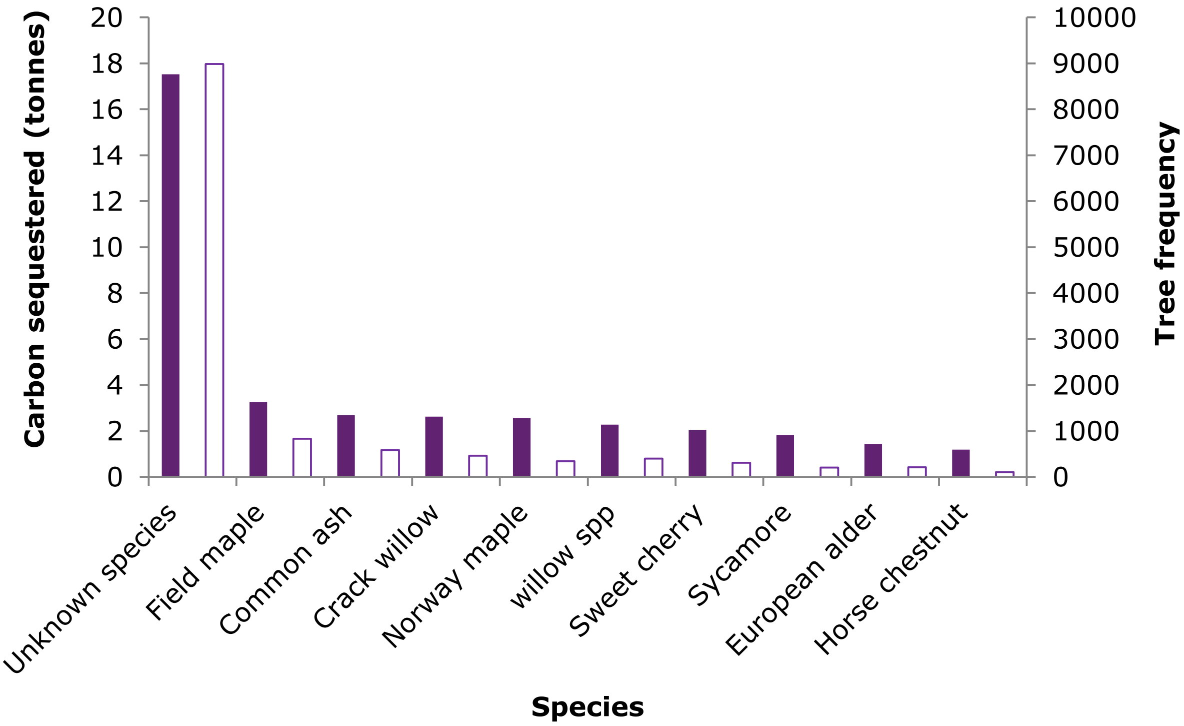


Figure 8. Amount of gross carbon sequestered by Bicester's public trees (bold bars) per year and the frequency of each species (blank bars) for those with greatest annual sequestration. The category 'unknown species' classifies all those that could not be matched to a certain species or genus.

Future work

A full Eco evaluation of Bicester's urban forest, encompassing random plots in public and private land, would improve the knowledge of its structure and the valuation of its economic benefits. This information could help Bicester council make informed plans for the management of its urban forest, ensuring its long term health and future.

Further analysis of Bicester's urban forest could:

- Generate a better picture of the structure of Bicester's urban forest including species diversity, canopy cover, size class, health/condition/life expectancy, species importance and leaf area
- Identify areas suitable for future tree planting
- Improve quantifications of the ecosystem services included in this short report
- Improve the valuations of the ecosystem services included in this short report
- Assess the value of the urban forest based upon its amenity
- Assess additional ecosystem services, such as habitat provision
- Evaluate the potential impact of tree pests and disease through a risk analysis.

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Appendix I - Detailed Methodology

Preparing data for entry into i-Tree Eco

Species data was matched to an i-Tree species code. To enable further analysis, trees that could not be matched (e.g. "Various", "Broadleaved mixed") were treated as a *Fraxinus*. The order of matching was therefore: Cultivar, Species, Genus and *Fraxinus* (Table A1).

Data were deleted:

- As indicated by guidelines from the Bicester and Beyond project
- Where DBH < 7 cm or was missing (671 out of the 6304 trees)
- Where there were duplicate tree group entries i.e. polygons overlaying each other. Where the polygons had different DBHs the average was used.

The number of trees in each tree group was calculated by assuming that each polygon represented multiple trees with an average DBH. To calculate the number of trees within a polygon, each tree was first classed as of small or large stature (Table A2). The coefficients found by Vaz Monteiro et al. (2016) for common curves relating crown width to DBH of small and large stature trees were then used to estimate the crown width of each individual tree present in the tree group (Table A3).

Canopy area for each tree was calculated with Equation 1. When estimating the number of trees from the total canopy area of a tree group, the tree group area was reduced by 10% to take account for gaps typical from a normal woodland canopy (Equation 2).

$$\text{Canopy area} = \pi\,(\text{Crown width}/2)^2 \qquad (1)$$

$$\text{Number of trees} = (\text{Tree group Area} * 0.9)/\text{Canopy area} \qquad (2)$$

All calculations of tree numbers were rounded down to the closest whole number (e.g. 2.6 was converted into 2).

Table A1. Codes attributed to the species provided (*as indicated in the database).

Species*	Common Name*	Matched Species	Code
Abies	Fir	Abies	AB
Acer	Maple	Acer	AC
Acer buergerianum	Trident Maple	Acer buergerianum	ACBU
Acer campestre	Field Maple	Acer campestre	ACCA
Acer campestre Elsrijk	Field Maple 'Elsrijk'	Acer campestre	ACCA
Acer cappadocicum		Acer cappadocicum	ACCA3
Acer cappadocicum 'Rubrum'		Acer cappadocicum	ACCA3
Acer davidii	Pere David's Maple	Acer davidii	ACDA
Acer negundo	Ash Leaf Maple	Acer negundo	ACNE
Acer platanoides	Norway Maple	Acer platanoides	ACPL
Acer platanoides 'Crimson King'	Norway Maple	Acer platanoides 'Crimson King'	ACPLCK
Acer platanoides 'Drummondi'	Norway Maple	Acer platanoides	ACPL
Acer platanoides 'Princeton Gold'	Norway Maple	Acer platanoides	ACPL
Acer pseudoplatanus	Sycamore	Acer pseudoplatanus	ACPS
Acer saccharinum	Silver Maple	Acer saccharinum	ACSA1
Aesculus hippocastanum	Horse Chestnut	Aesculus hippocastanum	AEHI
Aesculus x carnea	Red Horse Chestnut	Aesculus x carnea	AECA
Ailanthus altissima	Tree of Heaven	Ailanthus altissima	AIAL
Alnus cordata	Italian Alder	Alnus cordata	ALCO2
Alnus glutinosa	Common Alder	Alnus glutinosa	ALGL
Alnus glutinosa laciniata	Alder	Alnus glutinosa	ALGL
Alnus incana	Grey Alder	Alnus incana	ALIN
Alnus incana Aurea	Grey Alder Aurea	Alnus incana	ALIN
Amelanchier arborea Robin Hill	Snowy Mespil	Amelanchier	AM
Amelanchier arborea Robin Hill	Snowy Mespil	Amelanchier arborea	AMAR
Amelanchier lamarckii	Snowy Mespil	Amelanchier	AM
Betula ermanii	Erman's Birch	Betula	BE
Betula jacquemontii	Himalayan Birch	Betula	BE
Betula nigra	River Birch	Betula nigra	BENI
Betula pendula	Silver Birch	Betula pendula	BEPE
Betula pendula 'Dalecarlica'	Swedish Birch	Betula pendula	BEPE
Betula pendula youngii	Young's Weeping Birc	Betula pendula	BEPE
Betula pubescens	White Birch	Betula pubescens	BEAL1
Betula species	Birch	Betula	BE
Betula tristis	Weeping Silver Birch	Betula	BE
Betula utilis	Himalayan Birch	Betula utilis	BEUT2
Buxus sempervirens	Box	Buxus sempervirens	BUSE2
Carpinus betulus	Hornbeam	Carpinus betulus	CABE
Carpinus betulus 'Fastigiata'	Hornbeam	Carpinus betulus 'Fastigiata'	CABEFA
Castanea sativa	Sweet Chestnut	Castanea sativa	CASA2
Cedrus atlantica	Atlas Cedar	Cedrus atlantica	CEAT
Cedrus atlantica glauca	Atlas Cedar	Cedrus atlantica glauca	CEATGL
Cedrus deodara	Deodar Cedar	Cedrus deodara	CEDE
Cercis siliquastrum	Judas Tree	Cercis siliquastrum	CESI2
Chamaecyparis (unknown)	False Cypress	Chamaecyparis	CH
Chamaecyparis lawsoniana	False Cypress	Chamaecyparis lawsoniana	CHLA2
Chamaecyparis lawsoniana 'Erecta'	False Cypress	Chamaecyparis lawsoniana	CHLA2
Chamaecyparis lawsoniana 'Lutea'	False Cypress	Chamaecyparis lawsoniana	CHLA2
Cordyline spp	Cordyline	Cordyline	CO30
Cornus kousa chinensis	Jap Strawberry Tree	Cornus kousa	COKO
Cornus kousa 'Stella Pink'	Jap Strawberry Tree	Cornus kousa	COKO
Cornus sanguinea	Dogwood	Cornus sanguinea	COSA81
Corylus avellana		Corylus avellana	COAV
Corylus avellana	Hazel	Corylus avellana	COAV
Corylus colurna	Turkish Hazel	Corylus colurna	COCO2
Cotoneaster species	Cotoneaster	Cotoneaster	CO3
Crataegus crus-gallii	Cockspur Thorn	Crataegus crus-galli	CRCR
Crataegus laevigata	Midland Hawthorn	Crataegus laevigata	CRLA80
Crataegus monogyna	Common Hawthorn	Crataegus monogyna	CROX
Crataegus oxyacantha	Thorn	Crataegus	CR
Crataegus oxycantha 'Paul Scarlet'	Thorn	Crataegus	CR
Crataegus prunifolia	Broad-leaved Thorn	Crataegus prunifolia	CRPR1

Crataegus prunifolia 'Splendens'	Broad-leaved Thorn	Crataegus prunifolia	CRPR1
Crataegus species	Thorn	Crataegus	CR
Crataegus X grigonensis	Thorn	Crataegus x grignonensis	CRGR
Crataegus X lavellei camerei	Thorn	Crataegus x lavallei	CRLA
Cuppressus unknown species	Cypress	Cupressus	CU
Cupressocyparis leylandii	Cypress	Cupressocyparis leylandii	CULE
Cupressus macrocarpa	Monterey Cypress	Cupressus macrocarpa	CUMA
Eucalyptus gunnii	Gum Tree	Eucalyptus gunnii	EUGU
Fagus sylvatica	Beech	Fagus sylvatica	FASY
Fagus sylvatica Atropurpurea	Beech	Fagus sylvatica	FASY
Fagus sylvatica 'Dawyck'	Beech	Fagus sylvatica	FASY
Fagus sylvatica 'Dawyck Gold'	Beech	Fagus sylvatica	FASY
Fraxinus "Jaspidea"	Golden Ash	Fraxinus	FR
Fraxinus excelsior	Ash	Fraxinus excelsior	FREX
Fraxinus ornus	Manna Ash	Fraxinus ornus	FROR
Fraxinus oxycarpa	Caucasian Ash	Fraxinus oxycarpa	FROX
Fraxinus oxycarpa Raywood	Caucasian Ash	Fraxinus oxycarpa	FROX
Fraxinus species	Ash	Fraxinus	FR
Garrya elliptica	Garrya	Garrya elliptica	GAEL
Ginkgo biloba	Maidenhair Tree	Ginkgo biloba	GIBI
Gleditisia tricanthos 'Sunburst'	Honey locust	Gleditsia triacanthos 'Sunburst'	GLTRSU
Gleditisia tricanthos	Honey locust	Gleditsia triacanthos	GLTR
Ilex aquifolium	Holly	Ilex aquifolium	ILAQ
Ilex aquifolium argentea marginata	Holly	Ilex aquifolium	ILAQ
Juglans regia	Common Walnut	Juglans regia	JURE
Koelreuteria paniculata	Pride of India	Koelreuteria paniculata	KOPA
Laburnum species	Laburnum	Laburnum	LA2
Larix decidua	European Larch	Larix decidua	LADE
Ligustrum species	Privet	Ligustrum	LISP
Liquidambar styraciflua	Sweet Gum	Liquidambar styraciflua	LIST
Liquidamber styraciflua 'Thea'	Sweet Gum	Liquidambar styraciflua	LIST
Liquidamber styraciflua 'Worplesdon'	Sweet Gum	Liquidambar styraciflua	LIST
Liriodendron tulipifera	Tulip Tree	Liriodendron tulipifera	LITU
Liriodendron tulipifera variegata	Tulip Tree	Liriodendron tulipifera	LITU
Malus floribunda	Japanese Crab Apple	Malus floribunda	MAFL80
Malus orn. Crab	Apple	Malus	MA2
Malus species	Apple	Malus	MA2
Malus sylvestris	Crab Apple	Malus sylvestris	MASY2
Malus x purpurea	Apple	Malus x purpurea v eleyi	MAPUEL
Metasequoia glyptostroboides	Dawn Redwood	Metasequoia glyptostroboides	MEGL
Mixed broadleaves	Mixed broadleaves	Fraxinus	FR
Mixed broadleaves and conifers	Mixed broad/conif	Fraxinus	FR
Morus nigra	Black Mulberry	Morus nigra	MONI
Ostrya carpinifolia	Hop Hornbeam	Ostrya carpinifolia	OSCA
Parrotia persica	Persian Ironwood	Parrotia persica	PAPE
Parrotia persica Vanessa	Persian Ironwood	Parrotia persica	PAPE
Picea abies	Norway Spruce	Picea abies	PIAB
Picea breweriana	Brewer Spruce	Picea breweriana	PIBR4
Picea glauca	White Spruce	Picea glauca	PIGL1
Picea omorika	Oriental Spruce	Picea omorika	PIOM
Pinus nigra	Pine	Pinus nigra	PINI
Pinus nigra 'Austriaca'	Austrian Pine	Pinus nigra	PINI
Pinus species	Scot Pine	Pinus	PI2
Pinus sylvestris	Pine	Pinus sylvestris	PISY
Platanus x hispanica	Plane	Platanus	PL3
Populus alba	Poplar	Populus alba	POAL
Populus balsamifera	Poplar	Populus balsamifera	POBA
Populus canescens	Poplar	Populus canescens	POCA1
Populus nigra	Poplar	Populus nigra	PONI
Populus nigra 'Italica'	Poplar	Populus nigra 'Italica'	PONIIT
Populus species	Poplar	Populus	PO
Populus tremula	Poplar	Populus tremula	POTR10
Prunus 'Amanogawa'	Cherry	Prunus serrulata 'Amanogawa'	PRSEAM
Prunus avium	Cherry	Prunus avium	PRAV
Prunus avium 'Plena'	Cherry	Prunus avium	PRAV
Prunus cerasifera	Cherry Plum	Prunus cerasifera	PRCE

Prunus cerasifera 'Pissardii'	Purple-leaved Plum	Prunus cerasifera	PRCE
Prunus domestica	Plum	Prunus domestica	PRDO
Prunus 'Kanzan'	Cherry	Prunus	PR
Prunus laurocerasus	Cherry Laurel	Prunus laurocerasus	PRLA
Prunus lusitanica	Portugese Laurel	Prunus lusitanica	PRLU
Prunus padus	Cherry	Prunus padus	PRPA
Prunus pissardii Nigra	Cherry	Prunus pissardii	PRPI
Prunus sargentii	Cherry	Prunus sargentii	PRSA
Prunus serrulata	Cherry	Prunus serrulata	PRSE2
Prunus 'Shimidsu Sakura'	Cherry	Prunus	PR
Prunus 'Shirofugen'	Cherry	Prunus serrulata 'Shirotae'	PRSESO
Prunus species	Cherry	Prunus	PR
Prunus spinosa	Cherry	Prunus spinosa	PRSP2
Prunus subhirtella Autumnalis	Winter Flowering Cherry	Prunus subhirtella	PRSU
Prunus x hillieri Spire	Cherry	Prunus	PR
Prunus x 'Schmittii'	Cherry	Prunus	PR
Pyrus calleryana 'Chanticleer'	Pear	Pyrus calleryana 'Chanticleer'	PYCACH
Pyrus calleryana 'RedSpire'	Pear	Pyrus calleryana 'Red Spire'	PYCARS
Pyrus communis	Pear	Pyrus communis	PYCO
Pyrus species	Pear	Pyrus	PY
Quercus cerris	Oak	Quercus cerris	QUCE
Quercus ilex	Oak	Quercus/live ilex	QUIL2
Quercus palustris	Oak	Quercus palustris	QUPA
Quercus petrea	Oak	Quercus petraea	QUPE
Quercus robur	Oak	Quercus robur	QURO
Quercus rubra	Red Oak	Quercus rubra	QURU
Quercus species	Oak	Quercus	QU
Rhus typhrina	Sumach	Rhus	RHSP
Robinia pseudoacacia	False Acacia	Robinia pseudoacacia	ROPS
Robinia pseudoacacia 'Frisia'	False Acacia	Robinia pseudoacacia Frisia	ROPSFR
Salix alba	Willow	Salix alba	SAAL4
Salix babyloncia	Willow	Salix babylonica pekinensis	SABA1PE
Salix caprea	Willow	Salix caprea	SACA4
Salix fragilis	Willow	Salix fragilis	SAFR
Salix matsudana 'Tortuosa'	Willow	Salix matsundana tortuosa	SAMA1
Salix species	Willow	Salix	SA
Salix viminalis	Willow	Salix	SA
Salix x chrysocoma	Willow	Salix x chrysocoma	SACH
Sambucus nigra	Elder	Sambucus nigra	SANI4
Sequoia sempervirens	Coast Redwood	Sequoia sempervirens	SESE
Sequoiadendron giganteum	Giant Redwood	Sequoiadendron giganteum	SEGI
Sorbus aria	Whitebeam	Sorbus aria	SOAR
Sorbus aria 'Lutescens'	Whitebeam	Sorbus aria	SOAR
Sorbus aucuparia	Rowan	Sorbus aucuparia	SOAU
Sorbus aucuparia 'Edulis'	Rowan	Sorbus aucuparia	SOAU
Sorbus aucuparia Golden Wonder	Rowan	Sorbus aucuparia	SOAU
Sorbus cashmiriana	Sorbus	Sorbus	SO
Sorbus commixta	Sorbus	Sorbus commixta	SOCO
Sorbus commixta 'Embley'	Japanese Rowan 'Embley'	Sorbus commixta embley	SOCOEM
Sorbus hupehensis	Sorbus	Sorbus hupehensis	SOHU
Sorbus intermedia	Sorbus	Sorbus intermedia	SOIN
Sorbus latifolia Henk Vink	Rowan	Sorbus latifolia	SOLA
Sorbus species	Sorbus	Sorbus	SO
Sorbus torminalis	Wild Service Tree	Sorbus torminalis	SOTO
'Species not in list'	'Species not listed'	Fraxinus	FR
'Species not known'	'Species unknown'	Fraxinus	FR
'Suitable location for new tree'	'Suitable location'	Fraxinus	FR
Taxodium distichum	Swamp Cypress	Taxodium distichum	TADI
Taxus baccata	Yew	Taxus baccata	TABA
Taxus baccata 'Fastigiata'	Yew	Taxus baccata	TABA
Thuja occidentalis	Thuja	Thuja occidentalis	THOC
Thuja plicata	Thuja	Thuja plicata	THPL
Tilia cordata	Lime	Tilia cordata	TICO
Tilia cordata 'Greenspire'	Lime	Tilia cordata 'Greenspire'	TICOGR
Tilia mongolica	Lime	Tilia	TI
Tilia platyphyllos	Lime	Tilia platyphyllos	TIPL

Tilia platyphylos 'Rubra'	Lime	Tilia platyphyllos	TIPL
Tilia species	Lime	Tilia	TI
Tilia tomentosa	Lime	Tilia tomentosa	TITO
Tilia x euchlora	Lime	Tilia	TI
Tilia x europaea	Lime	Tilia x europaea	TIEU1
Ulmus carpinifolia 'Wredei Aurea'	Elm	Ulmus carpinifolia 'Hollandica'	ULCAHO
Ulmus glabra	Elm	Ulmus glabra	ULGL
Ulmus procera	Elm	Ulmus procera	ULPR
Ulmus species	Elm	Ulmus	ULS
Unknown Species - Broadleaf		Fraxinus	FR
Unknown Species - Broadleaf	Unknown Broadleaf	Fraxinus	FR
Unknown Species - Conifer	Unknown Conifer	Fraxinus	FR
Unknown Species - Ground Cover	Unknown Ground	Fraxinus	FR
Unknown Species - Understory	Unknown Understory	Fraxinus	FR
Various		Fraxinus	FR
Viburnum opulus 'Xanthocarpum'	Viburnum	Viburnum opulus	VIOP
Viburnum tinus	Viburnum	Viburnum tinus	VITI2
Xmas tree		Fraxinus	FR
		Fraxinus	FR

Table A2. Stature attributed to each code associated with polygons.

Matched Species	Code	Stature
Abies	AB	Large
Acer	AC	Medium
Acer buergerianum	ACBU	
Acer campestre	ACCA	Medium
Acer cappadocicum	ACCA3	
Acer davidii	ACDA	
Acer negundo	ACNE	Large
Acer platanoides	ACPL	Medium
Acer platanoides 'Crimson King'	ACPLCK	
Acer pseudoplatanus	ACPS	Large
Acer saccharinum	ACSA1	Large
Aesculus hippocastanum	AEHI	Large
Aesculus x carnea	AECA	Medium
Ailanthus altissima	AIAL	
Alnus cordata	ALCO2	Medium
Alnus glutinosa	ALGL	Medium
Alnus incana	ALIN	Medium
Amelanchier	AM	
Amelanchier arborea	AMAR	
Betula	BE	Medium
Betula nigra	BENI	
Betula pendula	BEPE	Medium
Betula pubescens	BEAL1	Medium
Betula utilis	BEUT2	Medium
Buxus sempervirens	BUSE2	Small
Carpinus betulus	CABE	Medium
Carpinus betulus 'Fastigiata'	CABEFA	
Castanea sativa	CASA2	Large
Cedrus atlantica	CEAT	
Cedrus atlantica glauca	CEATGL	
Cedrus deodara	CEDE	Large
Cercis siliquastrum	CESI2	
Chamaecyparis	CH	Small
Chamaecyparis lawsoniana	CHLA2	Small
Cordyline	CO30	
Cornus kousa	COKO	
Cornus sanguinea	COSA81	
Corylus avellana	COAV	Large
Corylus colurna	COCO2	Large
Cotoneaster	CO3	Small
Crataegus crus-galli	CRCR	
Crataegus laevigata	CRLA80	

Crataegus monogyna	CROX	Small
Crataegus	CR	Medium
Crataegus prunifolia	CRPR1	
Crataegus x grignonensis	CRGR	
Crataegus x lavallei	CRLA	Small
Cupressus	CU	Large
Cupressocyparis leylandii	CULE	Large
Cupressus macrocarpa	CUMA	Large
Eucalyptus gunnii	EUGU	Large
Fagus sylvatica	FASY	Large
Fraxinus	FR	
Fraxinus excelsior	FREX	Large
Fraxinus ornus	FROR	
Fraxinus oxycarpa	FROX	
Garrya elliptica	GAEL	
Ginkgo biloba	GIBI	
Gleditsia triacanthos 'Sunburst'	GLTRSU	
Gleditsia triacanthos	GLTR	
Ilex aquifolium	ILAQ	Small
Juglans regia	JURE	Medium
Koelreuteria paniculata	KOPA	
Laburnum	LA2	Medium
Larix decidua	LADE	Large
Ligustrum	LISP	
Liquidambar styraciflua	LIST	Large
Liriodendron tulipifera	LITU	
Malus floribunda	MAFL80	
Malus	MA2	Small
Malus sylvestris	MASY2	Small
Malus x purpurea v eleyi	MAPUEL	
Metasequoia glyptostroboides	MEGL	
Morus nigra	MONI	
Ostrya carpinifolia	OSCA	
Parrotia persica	PAPE	
Picea abies	PIAB	Large
Picea breweriana	PIBR4	
Picea glauca	PIGL1	
Picea omorika	PIOM	Medium
Pinus nigra	PINI	Large
Pinus	PI2	Large
Pinus sylvestris	PISY	Large
Platanus	PL3	Large
Populus alba	POAL	Large
Populus balsamifera	POBA	Medium
Populus canescens	POCA1	
Populus nigra	PONI	Large
Populus nigra 'Italica'	PONIIT	
Populus	PO	
Populus tremula	POTR10	
Prunus serrulata 'Amanogawa'	PRSEAM	
Prunus avium	PRAV	Small
Prunus cerasifera	PRCE	Small
Prunus domestica	PRDO	small
Prunus	PR	Small
Prunus laurocerasus	PRLA	Small
Prunus lusitanica	PRLU	Medium
Prunus padus	PRPA	Medium
Prunus pissardii	PRPI	Small
Prunus sargentii	PRSA	
Prunus serrulata	PRSE2	Small
Prunus serrulata 'Shirotae'	PRSESO	
Prunus spinosa	PRSP2	Small
Prunus subhirtella	PRSU	Small
Pyrus calleryana 'Chanticleer'	PYCACH	
Pyrus calleryana 'Red Spire'	PYCARS	
Pyrus communis	PYCO	Medium

Pyrus	PY	Medium
Quercus cerris	QUCE	Large
Quercus/live ilex	QUIL2	Large
Quercus palustris	QUPA	
Quercus petraea	QUPE	Large
Quercus robur	QURO	Large
Quercus rubra	QURU	Large
Quercus	QU	Large
Rhus	RHSP	Medium
Robinia pseudoacacia	ROPS	Medium
Robinia pseudoacacia Frisia	ROPSFR	
Salix alba	SAAL4	Large
Salix babylonica pekinensis	SABA1PE	
Salix caprea	SACA4	Large
Salix fragilis	SAFR	
Salix matsundana tortuosa	SAMA1	
Salix	SA	Large
Salix x chrysocoma	SACH	
Sambucus nigra	SANI4	Small
Sequoia sempervirens	SESE	
Sequoiadendron giganteum	SEGI	
Sorbus aria	SOAR	Medium
Sorbus aucuparia	SOAU	Medium
Sorbus	SO	Medium
Sorbus commixta	SOCO	
Sorbus commixta embley	SOCOEM	
Sorbus hupehensis	SOHU	
Sorbus intermedia	SOIN	Medium
Sorbus latifolia	SOLA	
Sorbus torminalis	SOTO	Medium
Taxodium distichum	TADI	
Taxus baccata	TABA	Medium
Thuja occidentalis	THOC	
Thuja plicata	THPL	Large
Tilia cordata	TICO	Medium
Tilia cordata 'Greenspire'	TICOGR	
Tilia	TI	
Tilia platyphyllos	TIPL	Large
Tilia tomentosa	TITO	
Tilia x europaea	TIEU1	Large
Ulmus carpinifolia 'Hollandica'	ULCAHO	
Ulmus glabra	ULGL	Large
Ulmus procera	ULPR	Large
Ulmus	ULS	Large
Viburnum opulus	VIOP	
Viburnum tinus	VITI2	

Table A3. Coefficients found by Vaz Monteiro et al. (2016) to estimate crown with from the DBH's of small and large stature trees. The equation used was: Crown width = *a* DBH^{b}.

Stature of trees	*a*	*b*
Small	0.71	0.66
Large	0.66	0.71

i-Tree Eco Models

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

- **Urban forest structure** (e.g., species composition, tree health, leaf area, etc.).
- **Amount of water intercepted by vegetation**
- **Amount of pollution removed** hourly by the urban forest and its associated per cent air quality improvement throughout a year. Pollution removal is calculated for ozone, sulphur dioxide, nitrogen dioxide, carbon monoxide and particulate matter (<2.5 microns; $PM_{2.5}$).
- **Total carbon stored and net carbon annually sequestered** by the urban forest.
- **Replacement cost of the forest**, as well as the value for air pollution removal and carbon storage and sequestration.

To calculate the volume of stormwater intercepted by vegetation an even distribution of rain is assumed. The calculation is split into three stages:

1. The volume of water intercepted by vegetation
2. The volume of water dripping from vegetation once their canopy has reached saturation, minus water evaporation from leaf surfaces during the rainfall event
3. The volume of water that evaporates from leaf surfaces after a rainfall event

The same process is then applied to water reaching impervious ground, with saturation of the holding capacity of the ground causing surface runoff. Pervious cover is treated similarly, but with a higher storage capacity over time. See Hirabayashi (2013) for full methods.

Processes such as the effect tree roots have on drainage through soil are not calculated as part of this model.

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

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

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 (Baldocchi, 1988; Baldocchi et al., 1987). As the removal of carbon monoxide and particulate matter by vegetation is not directly related to transpiration, removal rates (deposition velocities) for these pollutants were based on average measured values from the literature (Bidwell and Fraser, 1972; Lovett, 1994) that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50 per cent re-suspension rate of particles back to the atmosphere (Zinke, 1967).

Replacement costs were based on valuation procedures of the US Council of Tree and Landscape Appraisers (CTLA), which uses tree species, diameter, condition and location information (Nowak et al., 2002), in this case calculated using standard i-Tree inputs such as per cent canopy missing.

US Externality and UK Social Damage Costs

The i-Tree Eco model provides figures using US externality and abatement costs. These figures reflect the cost of what it would take a technology (or machine) to carry out the same function that the trees are performing, such as removing air pollution or sequestering carbon.

In 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 (i.e. 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. The unit values used were based on those given in DECC (2011). This approach gives higher values of 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 effects 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. This approach is termed 'the costs approach'. Values were taken from Defra (2010a) which are based on the Interdepartmental Group on Costs and Benefits (IGCB).

There are three levels of 'sensitivity' applied to the air pollution damage cost approach: 'High', 'Central' and 'Low'. This report uses the 'Central' scenario based on 2010 prices.

Furthermore, the damage costs presented exclude several key effects, as quantification and valuation is not possible or is highly uncertain. These are listed below (and should be highlighted when presenting valuation results where appropriate).

The key effects that have not been included are:

- Effects on ecosystems (through acidification, eutrophication, etc.)
- Impacts of trans-boundary pollution
- Effects on cultural or historic buildings from air pollution
- Potential additional morbidity from acute exposure to particulate matter
- Potential mortality effects in children from acute exposure to particulate matter
- Potential morbidity effects from chronic (long-term) exposure to particulate matter or other pollutants

Appendix II - Species Importance List

Table A4. Importance value of all species included in the dataset.

Species	Population (%)	Leaf Area (%)	Importance Value
Unknown species	55.20	32.70	87.90
Field maple	5.10	7.50	12.60
Common ash	3.60	6.50	10.10
Norway maple	2.10	6.80	9.00
Crack willow	2.80	3.50	6.40
Sycamore	1.20	4.20	5.50
willow spp	2.40	2.80	5.30
Sweet cherry	1.90	2.80	4.70
European alder	1.30	2.30	3.60
Goat willow	2.00	1.10	3.10
Silver lime	1.00	2.10	3.00
English yew	1.00	1.90	2.90
Horse chestnut	0.60	2.20	2.80
Little-leaf lime	0.80	1.50	2.30
English oak	1.00	1.30	2.30
common hawthorn	1.50	0.70	2.20
Whitebeam	1.10	0.90	2.00
Austrian pine	0.70	1.00	1.70
poplar spp	0.80	0.80	1.60
Silver birch	0.90	0.70	1.50
European hornbeam	0.60	0.90	1.50
apple spp	0.80	0.70	1.50
Grey poplar	0.70	0.80	1.50
European beech	0.30	1.10	1.30
plum spp	0.60	0.50	1.20
Rowan	0.60	0.50	1.00
common hazel	0.50	0.50	1.00
European black elderberry	0.70	0.30	0.90
sycamore spp	0.20	0.70	0.90
Scotch pine	0.50	0.40	0.90
Lawson cypress	0.30	0.50	0.90
lime spp	0.30	0.50	0.70
English holly	0.30	0.40	0.70
Cherry plum	0.30	0.50	0.70
Crimson king Norway maple	0.20	0.50	0.70
Common lime	0.20	0.50	0.70
European aspen	0.20	0.40	0.60
Black locust	0.20	0.40	0.60
White willow	0.20	0.40	0.60
English elm	0.20	0.30	0.50
birch spp	0.20	0.20	0.50
Golden weeping willow	0.20	0.30	0.50
European bird cherry	0.20	0.20	0.40
White poplar	0.10	0.30	0.40
elm spp	0.20	0.20	0.40
Lombardy poplar	0.30	0.10	0.40
mountain ash spp	0.20	0.10	0.30
Big-leaf lime	0.10	0.20	0.30
Italian alder	0.10	0.20	0.30
Common cherry laurel	0.20	0.10	0.30
Leyland cypress	0.10	0.10	0.30
English walnut	0.00	0.20	0.30
Balsam poplar	0.10	0.20	0.30
hawthorn spp	0.20	0.10	0.30
Tree of heaven	0.10	0.20	0.30
Swedish whitebeam	0.10	0.10	0.20
Giant sequoia	0.00	0.20	0.20
Purpleleaf plum	0.10	0.10	0.20
Fastigate hornbeam	0.10	0.10	0.20

Caucasian ash	0.10	0.10	0.20
Western redcedar	0.10	0.10	0.20
oak spp	0.10	0.10	0.20
Downy birch	0.10	0.10	0.20
Wych elm	0.00	0.10	0.20
Peking Willow	0.00	0.10	0.20
Common box	0.10	0.10	0.20
Callery pear Chanticleer	0.10	0.00	0.10
European crabapple	0.10	0.10	0.10
Sweetgum	0.10	0.00	0.10
Flowering ash	0.00	0.10	0.10
Cappadocian maple	0.00	0.10	0.10
maple spp	0.10	0.00	0.10
Cockspur hawthorn	0.10	0.00	0.10
Atlas cedar	0.00	0.10	0.10
Black poplar	0.00	0.10	0.10
pine spp	0.10	0.00	0.10
Downy serviceberry	0.10	0.00	0.10
Sunburst honeylocust	0.10	0.00	0.10
serviceberry spp	0.10	0.00	0.10
Monterey cypress	0.10	0.00	0.10
Northern red oak	0.00	0.00	0.10
European turkey oak	0.00	0.10	0.10
Tulip tree	0.00	0.10	0.10
Portugal laurel	0.00	0.00	0.10
Blackthorn	0.00	0.00	0.10
Blue atlas cedar	0.00	0.10	0.10
Sweet chestnut	0.00	0.10	0.10
Boxelder	0.00	0.00	0.10
European larch	0.00	0.10	0.10
Dawn redwood	0.00	0.00	0.10
Shirotae cherry	0.00	0.00	0.10
Broad-leaf cockspur thorn	0.00	0.00	0.10
Common plum	0.00	0.00	0.10
Red horsechestnut	0.00	0.10	0.10
Kwanzan cherry	0.00	0.00	0.10
cordyline spp	0.00	0.00	0.10
pear spp	0.00	0.00	0.10
Hop hornbeam	0.00	0.00	0.00
Black mulberry	0.00	0.00	0.00
Turkish hazelnut	0.00	0.00	0.00
false cypress spp	0.00	0.00	0.00
Cider gum eucalyptus	0.00	0.00	0.00
Holly oak	0.00	0.00	0.00
Silver maple	0.00	0.00	0.00
Arbol de judea	0.00	0.00	0.00
Durmast oak	0.00	0.00	0.00
Indian paper birch	0.00	0.00	0.00
Common pear	0.00	0.00	0.00
Grey alder	0.00	0.00	0.00
sumac spp	0.00	0.00	0.00
Persian ironwood	0.00	0.00	0.00
Eleyi crapapple	0.00	0.00	0.00
Norway spruce	0.00	0.00	0.00
Wild service tree	0.00	0.00	0.00
River birch	0.00	0.00	0.00
Northern white cedar	0.00	0.00	0.00
fir spp	0.00	0.00	0.00
Smooth hawthorn	0.00	0.00	0.00
Baldcypress	0.00	0.00	0.00
Deodar cedar	0.00	0.00	0.00
Honeylocust	0.00	0.00	0.00
Higan cherry	0.00	0.00	0.00
Pere david's maple	0.00	0.00	0.00
Sargent cherry	0.00	0.00	0.00
Tortured willow	0.00	0.00	0.00

cotoneaster spp	0.00	0.00	0.00
Brewer's weeping spruce	0.00	0.00	0.00
Goldenrain tree	0.00	0.00	0.00
cypress spp	0.00	0.00	0.00
Japanese rowan	0.00	0.00	0.00
Coast redwood	0.00	0.00	0.00
Pin oak	0.00	0.00	0.00
Japanese flower crabapple	0.00	0.00	0.00
Golden black locust	0.00	0.00	0.00
Hupeh rowan	0.00	0.00	0.00
privet spp	0.00	0.00	0.00
Wavyleaf silktassel	0.00	0.00	0.00
Trident maple	0.00	0.00	0.00
Kousa dogwood	0.00	0.00	0.00
golden chain tree spp	0.00	0.00	0.00
White spruce	0.00	0.00	0.00
Serbian spruce	0.00	0.00	0.00
Greenspire lime	0.00	0.00	0.00
Laurustinus	0.00	0.00	0.00
Callery pear 'Redspire'	0.00	0.00	0.00

Appendix III - Non-traded values for carbon stored

Table A5. Carbon values based on the UK government's non-traded carbon valuation method (central scenario). Values assume the structure of the urban forest remains the same over time.

	Year	Stored C (t)	Gross sequestered C (t)	Stored C (tCO2e)	Non-traded unit value (£/tCO2e) Central	Discount rate	Discount factor	Value of discounted stored (tCO2e) Central
	2016	1,271	53	4,659	63	3.5	1.00	295,181
1	2017	1,324	53	4,855	64	3.5	0.97	301,259
2	2018	1,377	53	5,050	65	3.5	0.93	306,964
3	2019	1,431	53	5,246	66	3.5	0.90	312,307
4	2020	1,484	53	5,441	67	3.5	0.87	317,302
5	2021	1,537	53	5,637	68	3.5	0.84	322,488
6	2022	1,591	53	5,833	69	3.5	0.81	327,277
7	2023	1,644	53	6,028	71	3.5	0.78	331,678
8	2024	1,697	53	6,224	72	3.5	0.75	335,699
9	2025	1,751	53	6,419	73	3.5	0.73	339,350
10	2026	1,804	53	6,615	74	3.5	0.70	342,642
11	2027	1,857	53	6,810	75	3.5	0.68	345,583
12	2028	1,911	53	7,006	76	3.5	0.65	348,185
13	2029	1,964	53	7,202	77	3.5	0.63	350,458
14	2030	2,017	53	7,397	78	3.5	0.61	352,411
15	2031	2,071	53	7,593	86	3.5	0.59	381,481
16	2032	2,124	53	7,788	93	3.5	0.57	409,696
17	2033	2,177	53	7,984	100	3.5	0.55	437,024
18	2034	2,231	53	8,180	108	3.5	0.53	463,438
19	2035	2,284	53	8,375	115	3.5	0.51	488,916
20	2036	2,337	53	8,571	122	3.5	0.49	513,439
21	2037	2,391	53	8,766	129	3.5	0.47	536,996
22	2038	2,444	53	8,962	137	3.5	0.46	559,576
23	2039	2,497	53	9,157	144	3.5	0.44	581,173
24	2040	2,551	53	9,353	151	3.5	0.43	601,785
25	2041	2,604	53	9,549	159	3.5	0.41	621,411
26	2042	2,658	53	9,744	166	3.5	0.40	640,055
27	2043	2,711	53	9,940	173	3.5	0.38	657,721
28	2044	2,764	53	10,135	180	3.5	0.37	674,418
29	2045	2,818	53	10,331	188	3.0	0.36	693,730
30	2046	2,871	53	10,526	195	3.0	0.35	712,265
31	2047	2,924	53	10,722	202	3.0	0.34	730,023
32	2048	2,978	53	10,918	210	3.0	0.33	747,004
33	2049	3,031	53	11,113	217	3.0	0.32	763,212
34	2050	3,084	53	11,309	224	3.0	0.31	778,651
35	2052	3,138	53	11,504	232	3.0	0.30	795,526
36	2053	3,191	53	11,700	240	3.0	0.29	810,746
37	2054	3,244	53	11,896	247	3.0	0.28	825,303
38	2055	3,298	53	12,091	255	3.0	0.27	839,087
39	2056	3,351	53	12,287	263	3.0	0.26	851,301
40	2057	3,404	53	12,482	270	3.0	0.26	862,916
41	2058	3,458	53	12,678	277	3.0	0.25	872,937
42	2059	3,511	53	12,873	284	3.0	0.24	881,728
43	2060	3,564	53	13,069	291	3.0	0.23	889,489
44	2061	3,618	53	13,265	298	3.0	0.23	896,083
45	2062	3,671	53	13,460	304	3.0	0.22	897,927
46	2063	3,724	53	13,656	309	3.0	0.21	899,207
47	2064	3,778	53	13,851	314	3.0	0.21	898,484
48	2065	3,831	53	14,047	318	3.0	0.20	896,647
49	2066	3,884	53	14,243	322	3.0	0.19	892,938
50	2067	3,938	53	14,438	326	3.0	0.19	888,117

Glossary of Terms

Biomass - the amount of living matter in a given habitat, expressed either as the weight of organisms per unit area or as the volume of organisms per unit volume of habitat

Broadleaf species – For example, alder, ash, beech, birch, cherry, elm, hornbeam, oak, other broadleaves, poplar, Spanish chestnut, and sycamore

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 through photosynthesis

Crown – The crown of a plant refers to the totality of the plant's aboveground parts, including stems, leaves, and reproductive structures

Diameter at Breast Height (DBH) - Tree DBH is outside bark diameter at breast height. Breast height is defined as 4.5 feet (1.37m) above the forest floor on the uphill side of the tree. For the purposes of determining breast height, the forest floor includes the duff layer that may be present, but does not include unincorporated woody debris that may rise above the ground line

Dieback - In dieback, a plant's stems die, beginning at the tips, for a part of their length. Various causes

Ecosystem services - The benefits people obtain from ecosystems

Height to crown base - In a silvicultural sense, crown base height is simply the height on the main stem or trunk of a tree representing the bottom of the live crown, with the bottom of the live crown defined in various ways

Leaf area index - Leaf Area Index (LAI) is the ratio of total upper leaf surface of vegetation divided by the surface area of the land on which the vegetation grows

Meteorological - Pertaining to meteorology or to phenomena of the atmosphere or weather

Particulate matter - The term used for a mixture of solid particles and liquid droplets suspended in the air. These particles originate from a variety of sources, such as power plants, industrial processes and diesel trucks. They are formed in the atmosphere by transformation of gaseous emissions

Phenology - The scientific study of periodic biological phenomena, such as flowering, breeding, and migration, in relation to climatic conditions

Re-suspension - The remixing of sediment particles and pollutants back into the water by storms, currents, organisms, and human activities, such as dredging

Structural value - value based on the physical resource itself (e.g. the cost of having to replace a tree with a similar tree)

Trans-boundary pollution - Air pollution that travels from one jurisdiction to another, often crossing state or international boundaries

Transpiration - Transpiration is the evaporation of water from aerial parts of plants, especially leaves but also stems, flowers and fruits

Tree-canopy - the aboveground portion of a plant community or crop, formed by plant crowns

Tree dry-weight - The plant, animal, or other material containing the chemical of interest is dried to remove all water from the material. The amount of the chemical found in subsequent analysis is then expressed as weight of chemical divided by weight of the dried material which once contained it

Volatile organic compounds - Any one of several organic compounds which are released to the atmosphere by plants or through vaporization of oil products, and which are chemically reactive and are involved in the chemistry of tropospheric ozone production