Teignbridge District Council i-Tree Eco Inventory and ORVal Greenspace Valuation Report

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August 2019

Executive Summary

Teignbridge's trees are generally recognised and appreciated for their amenity, presence and stature in the townscape, but society is often unaware of the many other benefits (or ecosystem services) that the trees provide to those who live and work there.
The trees in and around our urban areas are 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] (including the urban forest) 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. Yet, as the benefits provided by such natural capital are often poorly understood, they are often undervalued in the decision making process.

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

The data provided within the inventory did not include trees managed by housing associations or other highways institutions or private trees and was limited to the inventory provided by the local authority.

This is a partial analysis as not all of the benefits that trees provide were quantified or valued. For example the amenity benefits of trees have not been included in this report. Therefore the figures presented in this report should be regarded as a conservative estimate of the benefits of trees.

The ORVal tool, is an online application which has been "developed as a collaboration between the Land, Environment, Economics and Policy (LEEP) Institute at the University of Exeter and DEFRA". The tool aims to provide information which can enable benefits derived from accessible green space in England and Wales to be interpreted and analysed.

Highlights Include:

The public trees of Teignbridge remove over 130kg of air-borne pollutants each year and store over 5,380 tonnes of carbon.
The trees of Teignbridge divert an estimated 3,700 cubic meters of storm water runoff away from the local sewer systems each year. This is worth over £5,600 in avoided stormwater treatment costs annually.
The total structural replacement cost of the trees in the Teignbridge inventory currently stands at over £16 million. Table 1 (below) contains the headline figures.
The ORVal tool estimates that 10,614,213 visits are made to Teignbridge every year. The welfare value for Teignbridge stands at £38,848,000.

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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 inventories 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

Teignbridge Tree Inventory - Headline Figures	
Total Number of Trees Measured	7,000
Tree Canopy Cover	40.7 hectares
Most Common Species	Quercus robur, Fraxinus excelsior, Acer pseudoplatanus
Replacement Cost	£16,070,000
ORVal (Outdoor Recreational Value Tool)	
Estimated Welfare Value of Teignbridge	£38,848,000
Estimated Visits to Teignbridge	10,614,000
CAVAT (Capital Asset Value for Amenity Trees)	
Estimated total public amenity asset value	£144,000,000

Annual Quantities and Values		
Carbon Storage	5,375 tonnes	£1,321,000
Pollution Removal	130 kg	£9,970
Carbon Sequestration	102 tonnes	£6,800
Avoided Runoff	3,701m³	£5,600
Total Annual Benefits	£22,370	

Table 1: Headline figures.

Total Number of Trees Measured: Not all records supplied were used in the analysis. 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 with Leaf Area Index (LAI) which is the total surface area of leaves). This is not the total canopy cover for Teignbridge 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 (CTLA) Methodology guidance from the Royal Institute of Chartered Surveyors.
Estimated Welfare Value and Visitation: Is calculated by the ORVal tool, using the statistical model described within the ORVal section.
CAVAT: Is calculated using a method developed in the UK to provide a value for the public amenity that trees provide using the CTLA guidance.
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 CO_2e and the DECC figures of £67 per metric ton for 2019.
Pollution removal: This value is calculated based on the UK social damage costs (2019) for ‘Transport outer conurbation’ and the US externality prices where UK figures are not available; £0.984 per Kg (carbon monoxide - USEC), £0.49 per Kg (ozone - USEC), £13.20 per Kg (nitrogen dioxide - UKSDC), £6.27 per Kg (sulphur dioxide - UKSDC), £250.22 per Kg (particulate matter less than 2.5 microns - UKSDC). Values calculated using an exchange rate of $0.75 = £1.00.
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 £1.516 per cubic metre and includes the cost of the avoided energy and associated greenhouse gas emissions in treating the water.

Data processed using i-Tree Eco Version 6.1.27.

Methodology

Teignbridge's tree inventory, supplied by Teignbridge Council (which included 7,744 entries, all of them referring to trees in public land) was reformatted and uploaded into Eco. Amongst the data collected were tree species and stem diameter.

The minimum data required by Eco is tree species and stem diameter (dbh). However, the more data that is available for each tree (height and crown spread for example), the more accurate the model calculations will be.

Of the original 7,744 records, 7,000 were suitable for import. Reasons for removal included no dbh, no species, or trees recorded as a group of 'Mixed spp.' for example.
There were 8 records where the decimal place had been recorded incorrectly resulting in an inaccurate dbh value, these were corrected.
The Eco software also requires data to be input in a particular format with values over 0 for all the structural data of each tree. Some estimates had to be inputted based on the information available within the provided tree inventory.

The inventory data was processed within Eco using the in-built local pollution and climate data from 2013 and the Exeter weather station to provide the following outputs (listed in Table 2 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, this service is not valued or included in the report.
Structural and Functional values	Replacement Cost in £. Carbon storage value in £. Carbon sequestration value in £. Pollution removal value in £. Avoided runoff in £.

Table 2: Study Outputs

For each category the top ten performing species (based on the trees performance rather than their quantity or size) were used for charts and tables within this report. However, all other figures for the remaining 169 species are available within the Eco files for this project. For a more detailed description of the model calculations see Appendix IV.

Results Section -Tree Population Characteristics

Tree Species

Teignbridge's tree inventory has a large diversity of tree species (179). However a small number of species dominate (see figure 1 below). 11.5% of the 7,000 trees in Teignbridge's tree inventory are English oak (*Quercus robur*) and the second, third and fourth most common trees are respectively: Ash (*Fraxinus excelsior* – 8.3%), Sycamore (*Acer pseudoplatanus* – 5.9%) and Silver birch (*Betula pendula* – 4.9%).

The large diversity of tree species (179) within Teignbridge's tree inventory creates relatively low percentages for the most common species observed in the chart and a high percentage for the 'all other species' category (see Appendix II).

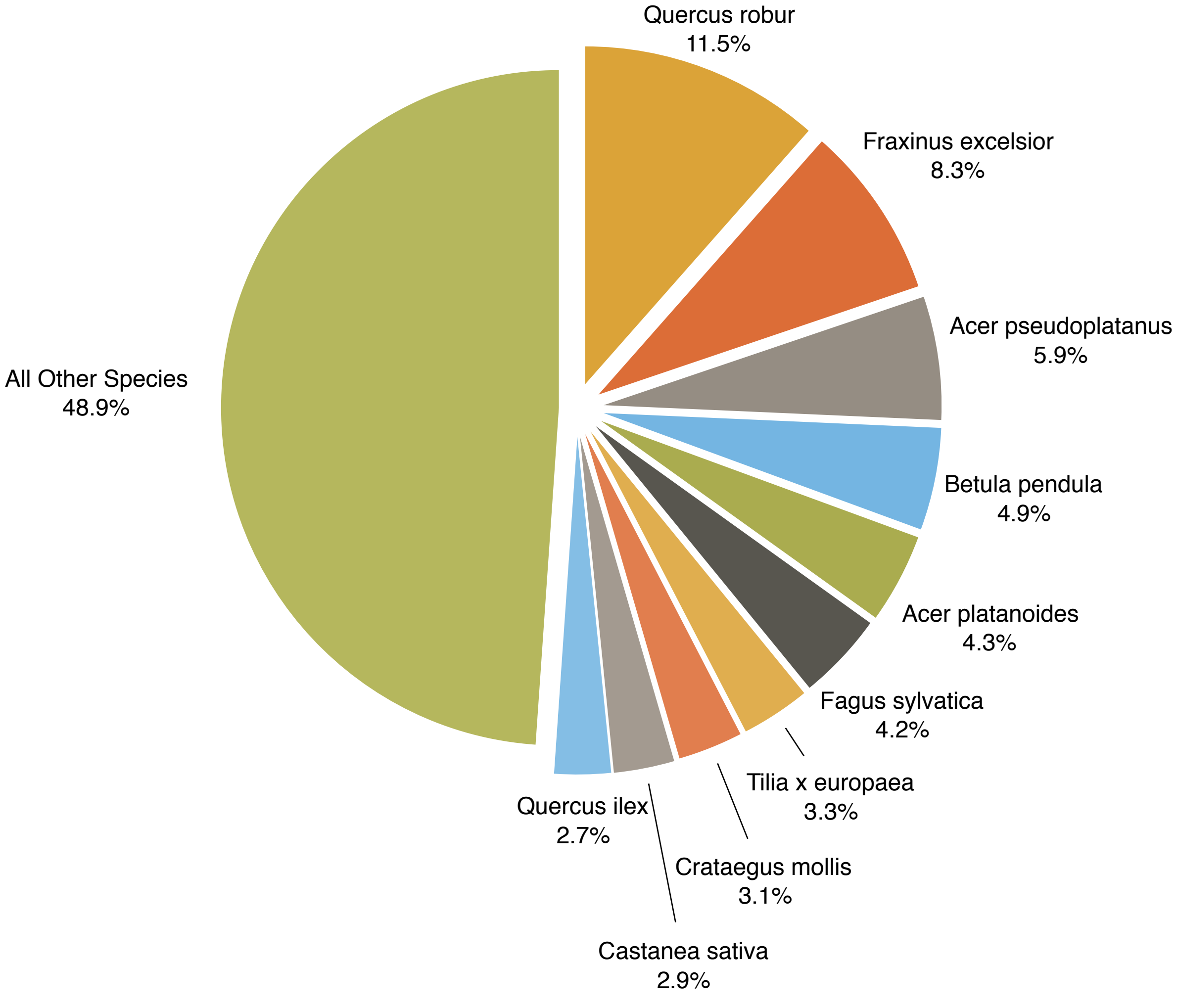

Figure 1: Percentage composition of tree species

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. Diversity includes both the individual diversity within a tree species (i.e. genetic diversity) and between different tree species in terms of different genera or families (e.g. *Acer* (maple family); *Fraxinus* (Ash family).

A more diverse tree-scape is better able to deal with possible changes in climate or potential pest and disease impacts. This is because with more diverse tree populations the likelihood that they will all be vulnerable to a particular threat is lower, and therefore a smaller proportion will be detrimentally affected. The tree population within Teignbridge's tree inventory represents a fairly rich community of trees given the area, with 179 species of tree listed.

Tree species from 6 continents are represented in Teignbridge's tree inventory, most of the species are native to Europe & Asia (see figure 2 below).

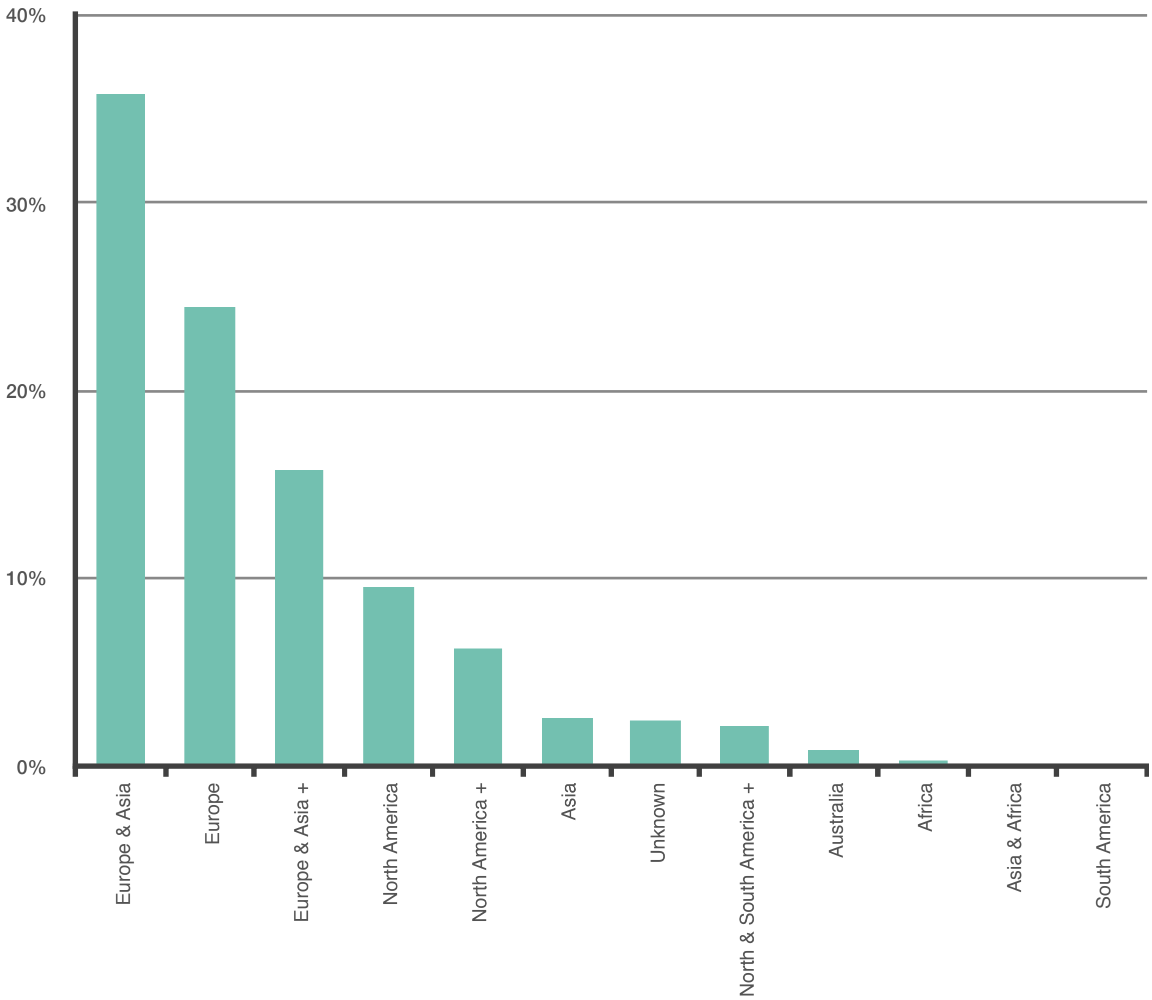

Figure 2: Origin of tree species

Note: The + sign indicates that the species is native to more than one continent. 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 inventory trees were sized by their stem diameter. 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 Teignbridge's tree inventory appears to show a large volume of younger trees. There appears to be a good proportion of the oak and beech trees being semi or mature trees, providing a large amount of ecosystem services to Teignbridge. The size distribution of the tree stock will improve over time and would benefit from continued planting to replace the mature trees as they die. Improving structural diversity increases the overall resilience of the tree stock.

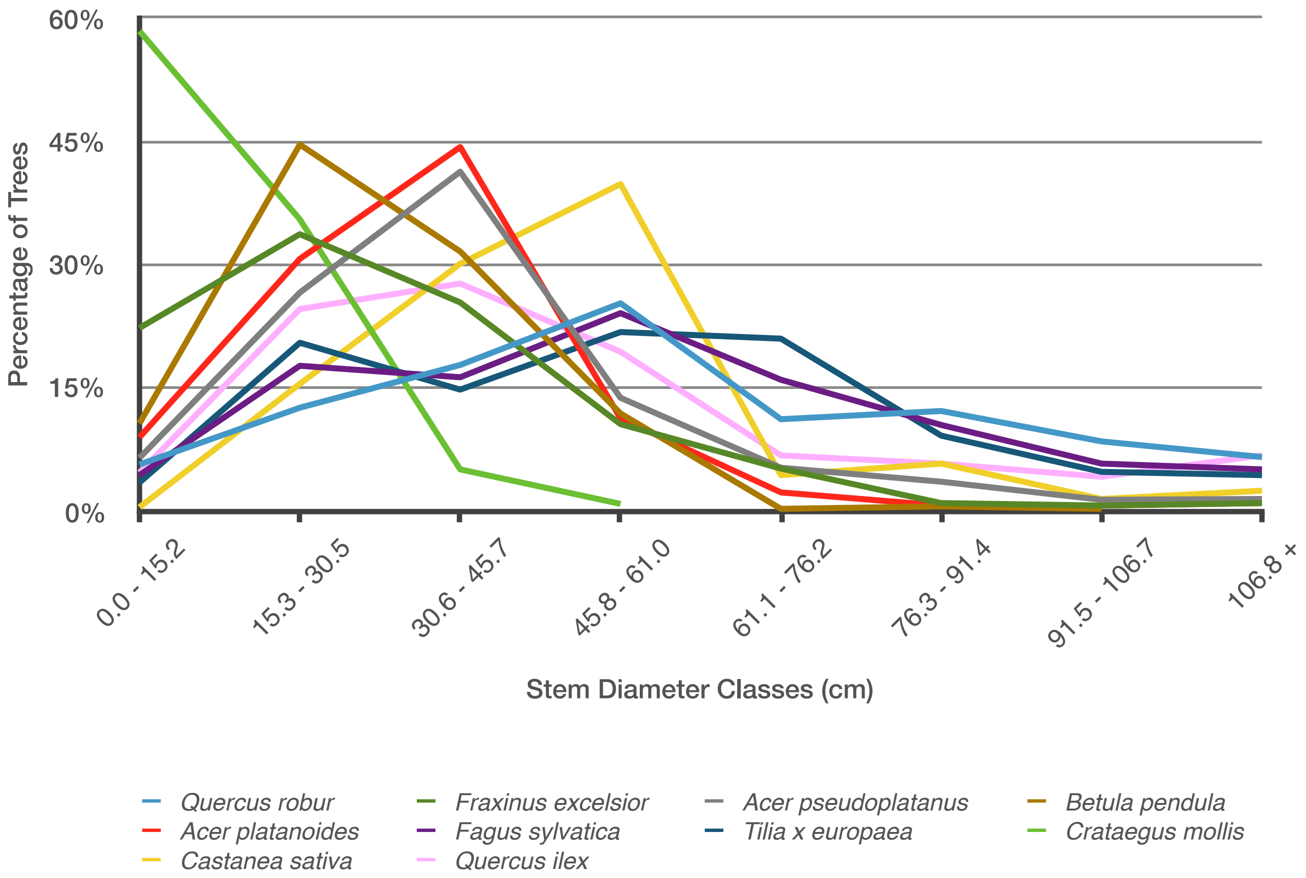

Figure 3: Composition (%) of tree population by stem diameter

Leaf Area and Population

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

Within Teignbridge's tree inventory, total leaf area is estimated at 1,926,900m^2. If all the layers of leaves within the tree canopies were spread out, they would cover an area nearly 4 times the size of Stover Country Park.

The three most dominant species in terms of leaf area are English oak (*Quercus robur* - which has 17.9% of the total leaf area for all trees), Beech (*Fagus sylvatica* - 9.6%) and Sycamore (*Acer pseudoplatanus* - 7.9%).

Figure 4 (below) shows the top ten dominant trees' contributions to total leaf area. In total these ten species, representing 49.6% of the tree population, contribute 65.6% of the total leaf area.

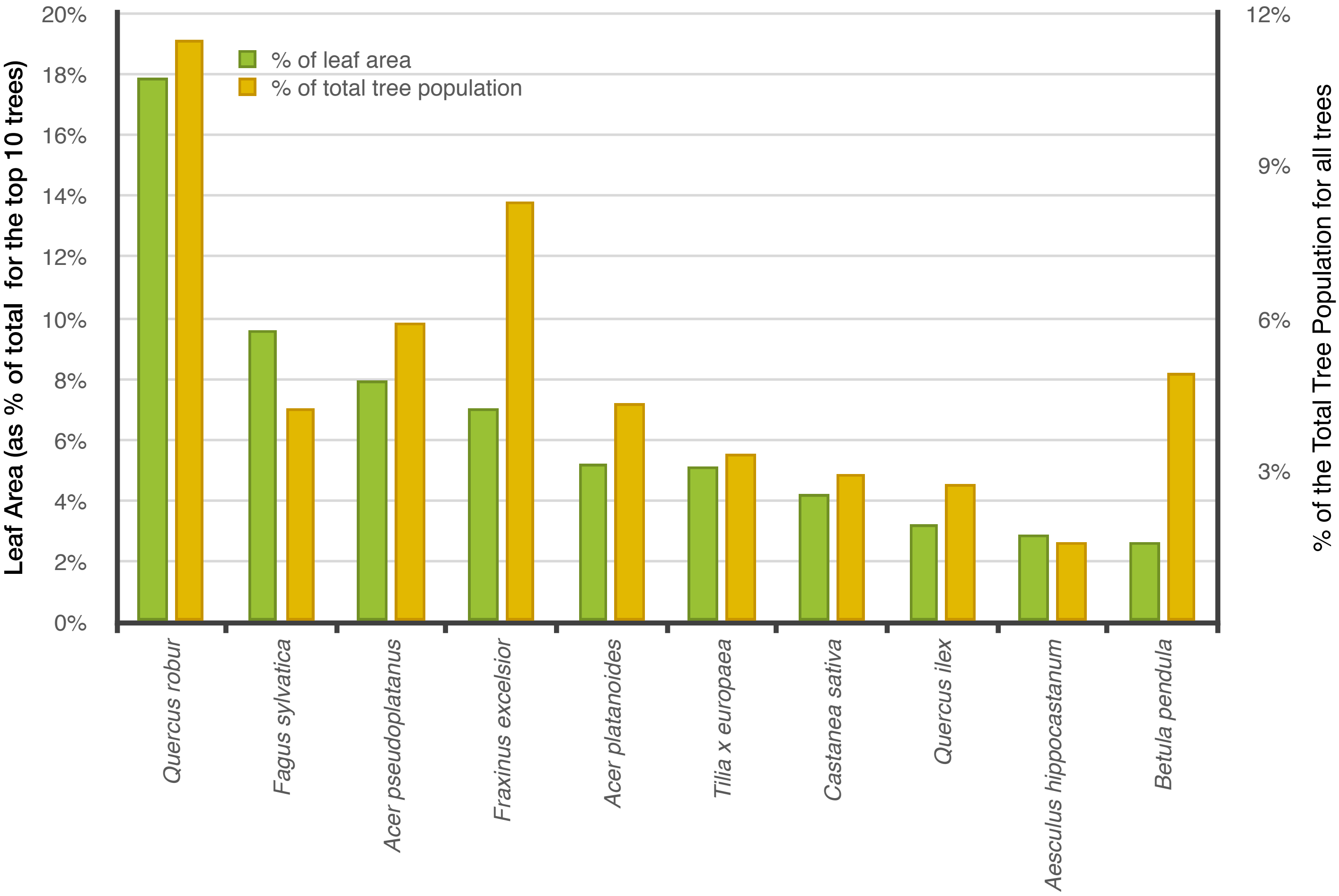

Figure 4: Percentage leaf area and population of the ten most dominant trees

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 severe health problems in humans to damage to buildings[5].

Urban trees can help to improve air quality by reducing air temperature and removing pollutants[6]. Trees intercept and absorb airborne pollutants on to the leaf surface[7]. In addition, by removing pollution from the atmosphere, trees reduce the risks of respiratory disease and asthma, thereby contributing to reduced health care costs[8].

Trees also emit volatile organic compounds (VOCs) that can contribute to low-level ozone formation which is detrimental to human health. However, integrated studies have revealed that an increase in tree cover leads to a general reduction in ozone through a reduction in air temperature[9]. Eco accounts for both reduction of ozone and production of VOCs within its algorithms, and as shown in figure 5 Eco estimated that Teignbridge's trees remove more ozone than they contribute.

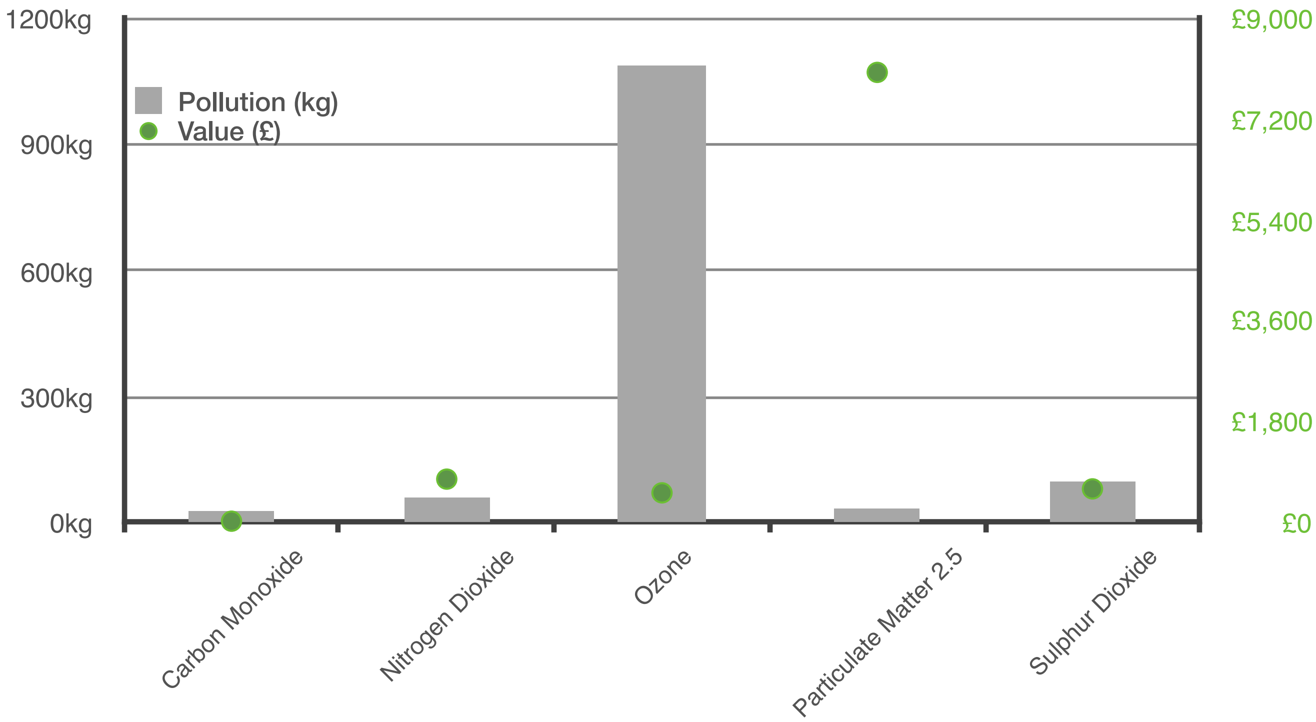

Figure 5: Value of the pollutants removed and quantity per-annum within Teignbridge's tree inventory

Note: Valuation methods used are UK social damage cost (UKSDC) for NO2, PM2.5 & SO2 - the US externality cost (USEC) is used for CO & O3.

[5] Nowak et al., 2000

[6] Tiwary et al., 2009

[7] Nowak et al., 2000

[8] Peachey et al., 2009. Lovasi et al., 2008

[9] Nowak et al., 2006, Escobedo and Nowak 2009

Increasing areas of tree planting and so canopy cover has been shown to make further improvements to air quality. Furthermore, because the amount of airborne pollutants captured by a tree increases with 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 Teignbridge's tree inventory. As different species can capture different sizes of particulate matter,[10] it is recommended that a broad range of species should be considered for planting in any air quality strategy.

The English oak (*Quercus robur*) removes the largest percentage (17.9%) of the pollution for the whole inventory. This reflects the maturity of this section of the Teignbridge tree population. As the younger trees grow, the reliance on the oak to deliver ecosystem services will decline.

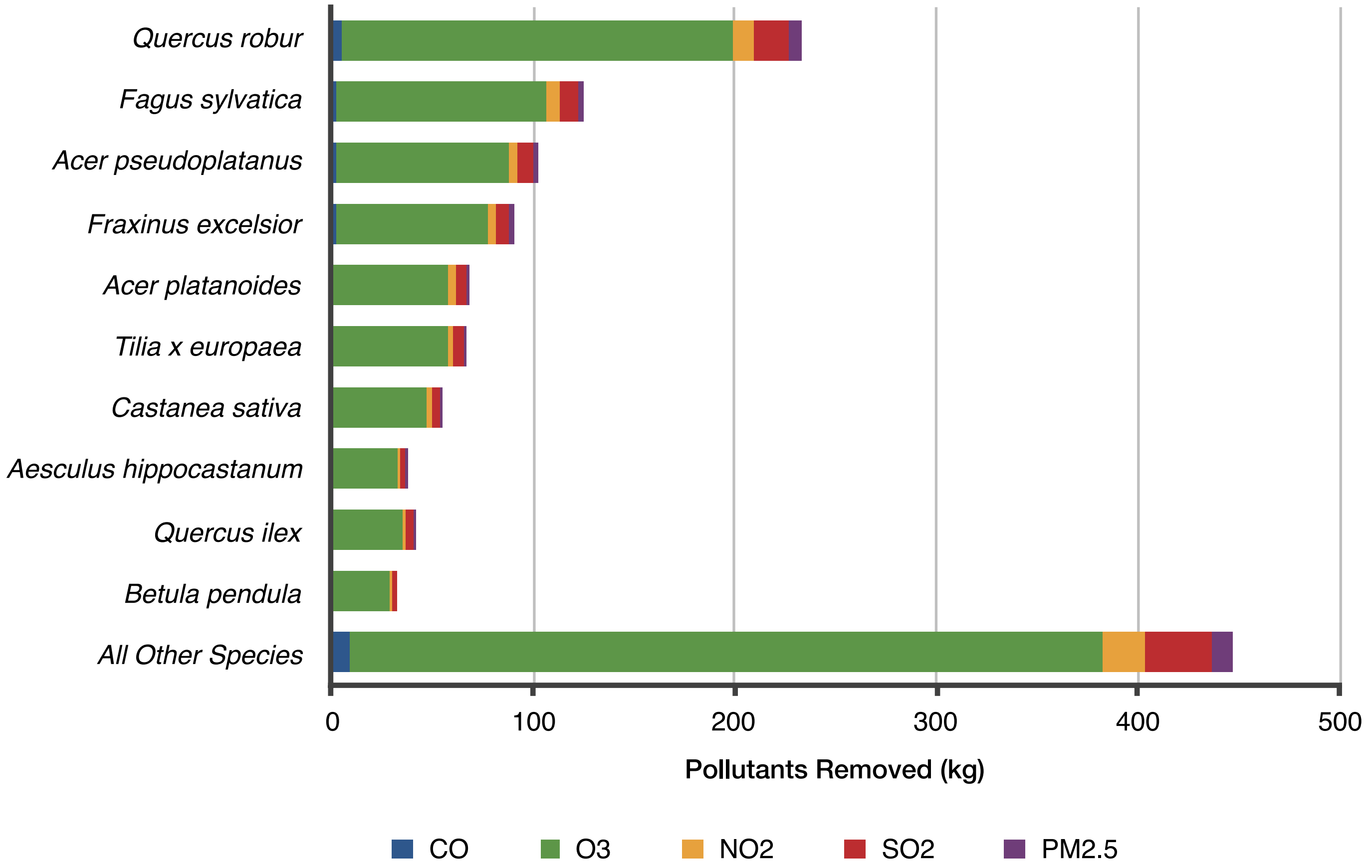

Figure 6: Pollution removal by tree species

[10] Freer-Smith et al. 2005

With regard to individual tree species performance, i-Tree Species (a stand alone web based tool) can be used to calculate the best tree species to use, based on the potential environmental services required. The program calculates the best tree species based on the user-provided weighting of environmental benefits of tree species at maturity and the geographical area.

Species are selected based on three types of information: Hardiness – as determined by region and/or city; mature height – user specified minimum and maximum heights; environmental factors – ranked from 0 to 10. In this instance air pollution removal was selected as the sole criteria to provide a ranked list of the best 'pollution busting' trees, see table 3 (below).

Species	Ranking	No. Of trees in inventory
Liriodendron tulipifera	1	11
Cedrus deodara	2	16
Aesuclus hippocastanum	3	114
Acer platanoides	4	300
Corylus colurna	5	0
Picea rubens	6	0
Tilia tomentosa	7	1
Picea abies	8	5
Fraxinus excelsior	9	578
Carpinus betulus	10	50

Table 3: Top ten best pollution removing species in Teignbridge

Comparing the list in table 3 with the results from Teignbridge's tree inventory, there are eight species within the top ten pollution removing trees (highlighted in red). To maximise the potential pollution removal in the future, it would be worth continuing to plant these species listed in table 3. Of course, local needs and site limitations would also need to be taken into account.

Please note: At the time of writing, phyto-sanitary controls put in place by the authorities in the UK currently mean that both *Fraxinus excelsior* and *Aesculus hippocastanum* are unavailable as young trees.

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 several tons of carbon for decades or even centuries[11] .

Overall the trees in the Teignbridge inventory store an estimated 5,375 tonnes of carbon with a value of £1,320,637. This quantity and value should increase over time as trees grow.

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

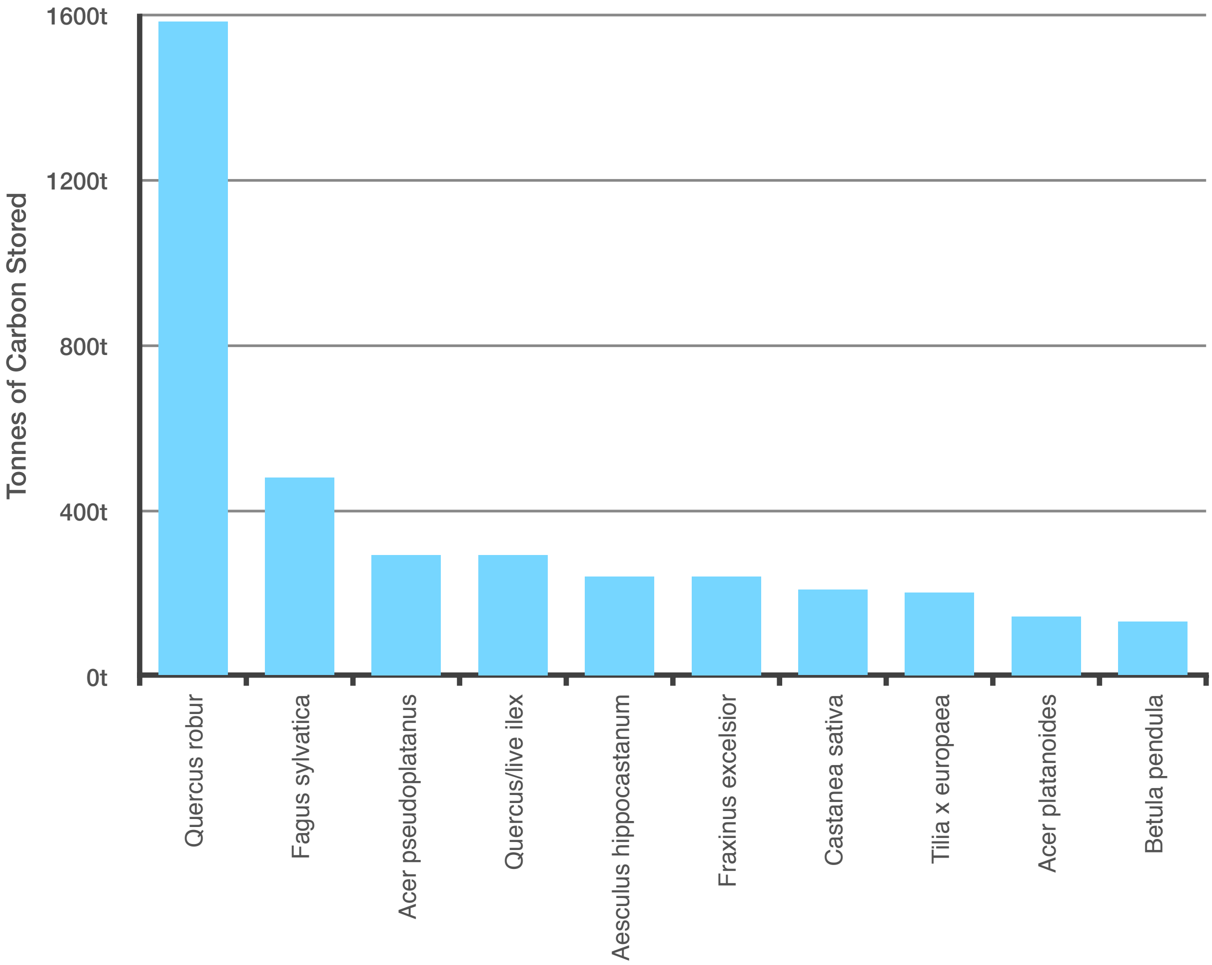

Figure 7: Carbon storage (tonnes) for top ten tree species

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 and a good tree size distribution 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, in particular where energy is produced by fossil-fuel burning power plants.

[11] Kuhns 2008, 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 measure (converted to volume) of tree growth. This volume is then converted into tonnes of carbon based on species specific conversion factors, it is then converted to CO_2 equivalent before being multiplied by the unit cost for carbon. The current (2019) UK social cost is £67 / tonne.

Teignbridge's tree inventory trees sequester an estimated 101.6 tonnes of carbon per year, with a value of £24,968. Table 4 (below) shows the ten 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)	CO_2 Equivalent (tonnes/yr)	Carbon Sequestration (£/yr)
Quercus robur	24	88	£5,907
Fagus sylvatica	8	28	£1,885
Acer pseudoplatanus	6	23	£1,554
Fraxinus excelsior	6	21	£1,376
Betula pendula	4	16	£1,079
Quercus ilex	4	16	£1,049
Castanea sativa	4	15	£1,032
Acer platanoides	4	14	£918
Aesculus hippocastanum	4	13	£860
Tilia x europaea	3	13	£847
All Other Species	34	126	£8463
Total	102	373	£24,968

Table 4: Carbon sequestration by species

Of the entire tree species inventoried, the English oak (*Quercus robur*) stored and sequestered the most carbon. During this growing season alone, English oak contributed ca.24 tonnes of carbon.

For comparison, the average newly registered car in the UK produces 34g carbon per km[12]. Carbon sequestration in Teignbridge's tree inventory therefore accounts for around 2,989,118 'new' vehicle km per year.

[12] http://naei.beis.gov.uk/data/emission-factors
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/454981/veh0150.csv/preview

Avoided Runoff

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

In urban areas, the large extent of impervious surfaces increases the amount of runoff. However, trees are very effective at reducing this[14]. The trees' canopy intercepts precipitation, while the root system promotes infiltration and storage of water in the soil.

Annual avoided surface runoff in Eco is calculated based on rainfall interception by vegetation, specifically the difference between annual runoff with and without vegetation. The trees within Teignbridge's tree inventory reduce runoff by an estimated 3,700 m^3 a year with an associated value of £5,600.

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

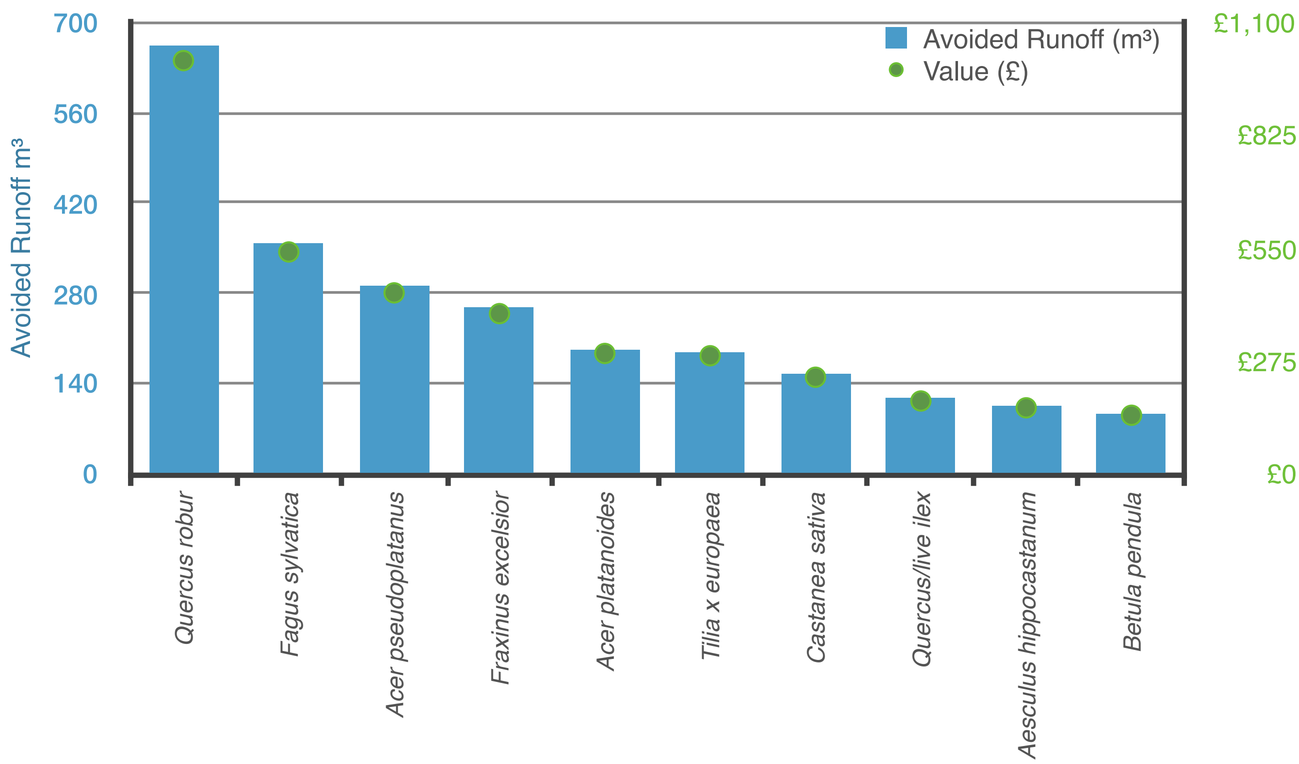

Figure 8: Avoided runoff by top ten species

The trees in Teignbridge's tree inventory play an important role in reducing runoff: The English oak (*Quercus robur*) intercepts the largest proportion of the precipitation for a species and is, by a considerable margin, the most important species in this category. This is due to the trees' population, canopy size and leaf morphology.

[13] Hirabayashi 2012

[14] Trees in Hard Landscapes (TDAG) 2014

Potential Pests and Diseases

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

In this instance Asian Long Horn Beetle (ALB - a wood-boring insect) and Ash dieback (*Hymenoscyphus fraxineus*) have been selected to illustrate how the results from this survey can be used to estimate the potential impacts on the trees in Teignbridge.

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

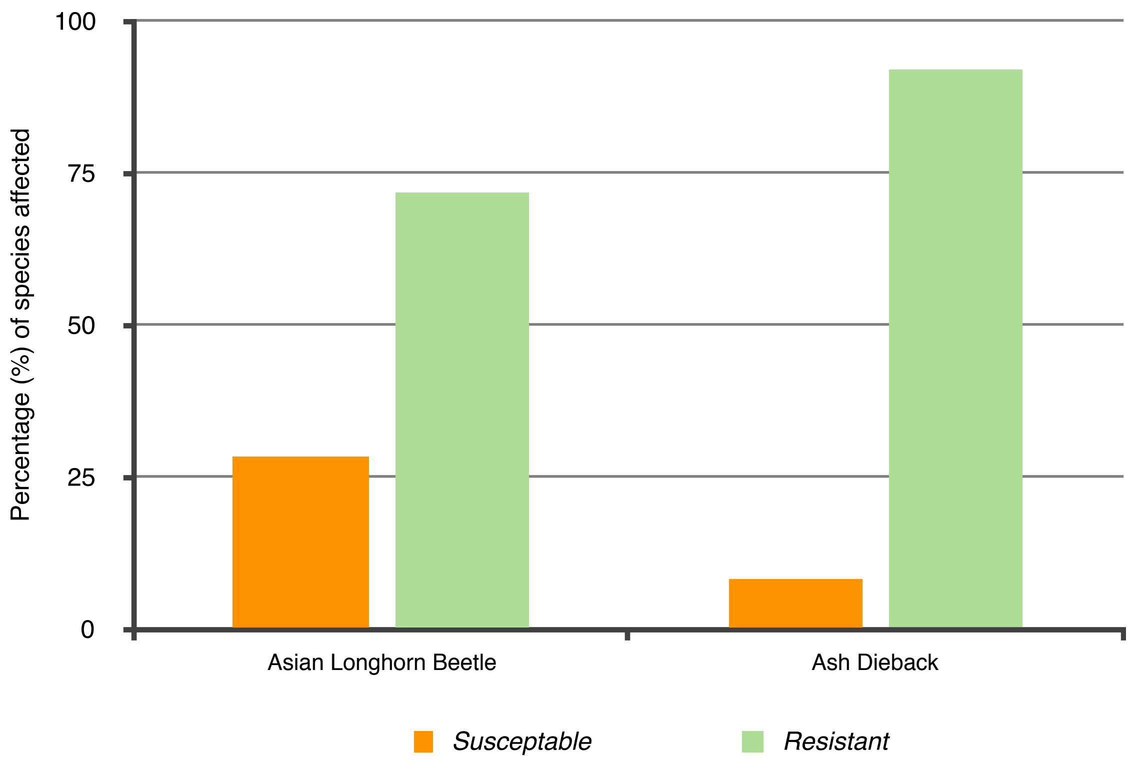

Figure 9: Potential pest impacts on Teignbridge's tree population

ALB is an insect that bores into the wood of a wide range of hardwood tree species, sometimes causing the collapse and mortality of parts of the host tree. This beetle could affect around 28.3% (or 1981) of the trees in the Teignbridge inventory, including the Sycamore (*Acer pseudoplatanus*) which makes up around 5.9% of the tree population.

This beetle has 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.

Ash dieback *(Hymenoscyphus fraxineus)* is harmless in its native range in Asia, associating with native ash species including *Fraxinus mandshurica*. However, European ash *(Fraxinus excelsior)* has shown to be highly susceptible to the pathogenicity of *H fraxineus. F excelsior* is the 2nd most common species in Teignbridge's tree inventory, accounting for 8.3% of the population (or

578 trees). Ash trees can be large in stature and provide a significant amount of ecosystem services to Teignbridge and so their replacement should they perish would be costly (Figure 10).

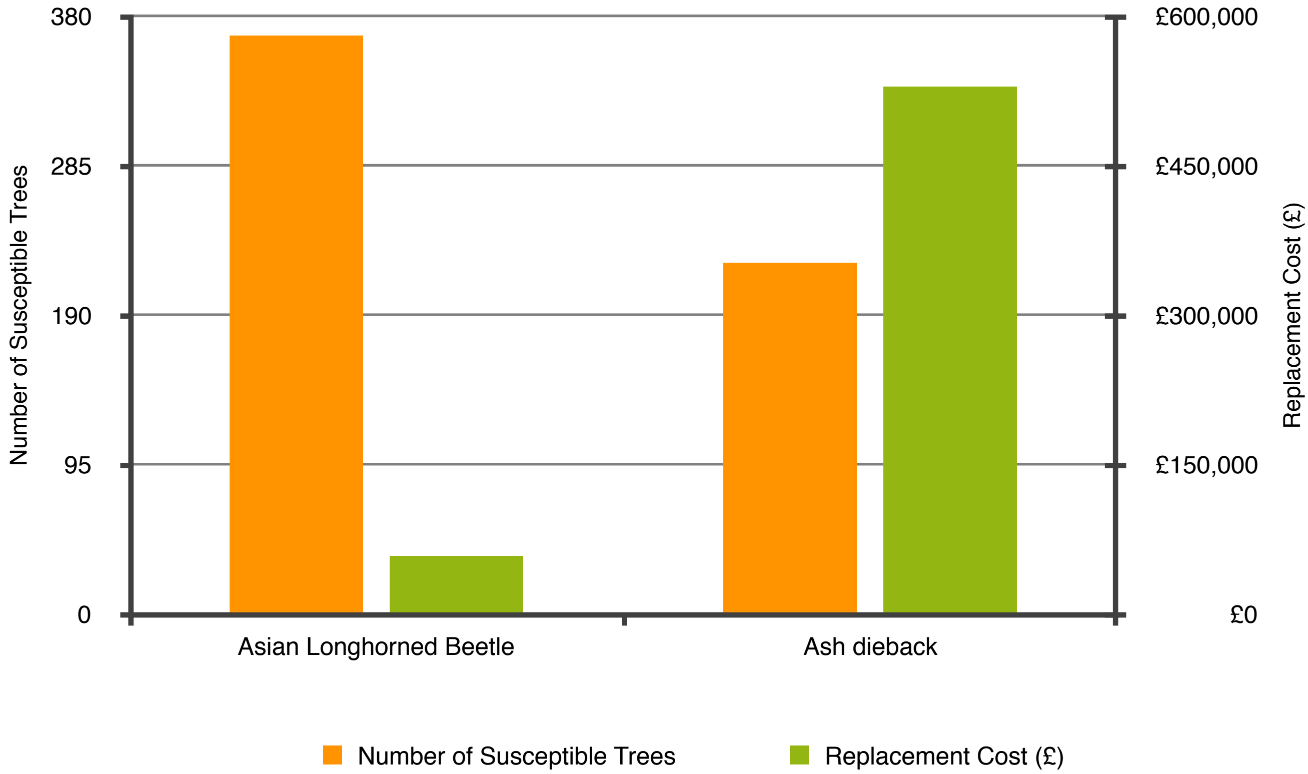

Figure 10: Potential replacement cost of pest impacts

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[15].

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 replacement cost of all trees in the study area as estimated by Eco currently stands at £16,069,583. English oak (*Quercus robur)* is, by far, the most valuable species of tree, on account of both its size and population, followed by the Beech (*Fagus sylvatica*) and Lime (*Tilia x europaea*). These three species of tree account for £5,987,000 (37.3%) of the total replacement cost of the trees in Teignbridge's tree inventory, with the English oak alone accounting for nearly 23.7% of this total replacement cost.

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

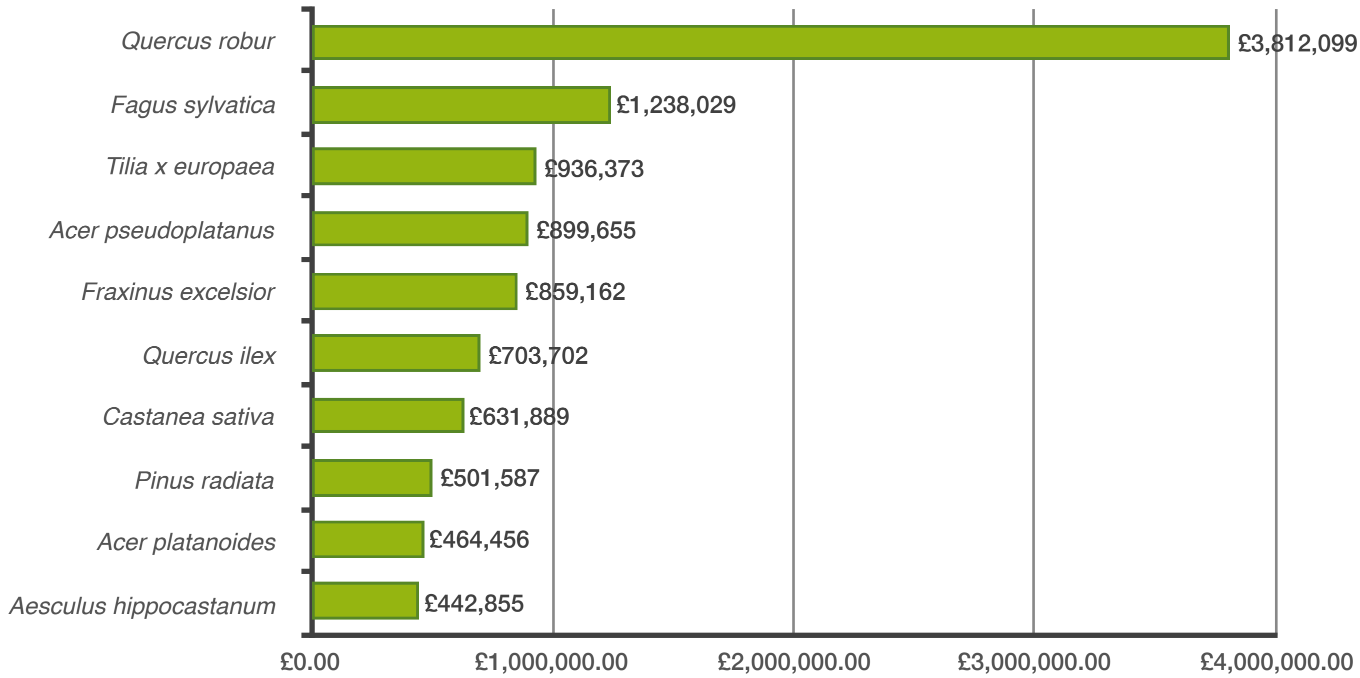

Figure 11: Replacement cost for the top ten trees in the inventory

15 Hollis, 2007

CAVAT - The amenity value of trees

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

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

For the public urban forest of Teignbridge, the estimated total public amenity asset value is over £144 million.

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

This study also included assumptions of condition and Safe Useful Life Expectancy (SULE), as this was not included in the Teignbridge tree inventory information.

The English oak (*Quercus robur*) of Teignbridge holds the highest CAVAT value (Table 4, below), and represents 11.5% of the total tree population.

Species	CAVAT Value	Percent of Total Population	Replacement Cost
Quercus robur	£32,060,949	11.5%	£3,812,099
Fagus sylvatica	£10,113,680	4.2%	£1,238,029
Tilia x europaea	£7,592,808	3.3%	£936,373
Acer pseudoplatanus	£7,589,593	5.9%	£899,655
Fraxinus excelsior	£7,534,151	8.3%	£859,162
Quercus/live ilex	£6,302,859	2.7%	£703,702
Aesculus hippocastanum	£5,332,488	1.6%	£442,855
Castanea sativa	£5,230,808	2.9%	£631,889
Pinus radiata	£4,950,500	1.1%	£501,587
Acer platanoides	£4,053,755	4.3%	£464,456

Table 4: The ten species with the highest CAVAT valuation

ORVal - Outdoor Recreational Value

Context

Teignbridge is located within South Devon and covers an area of 67,387ha. The district has a total of 24 wards and a varied land cover including, market towns, moorland, countryside and coastline[16].

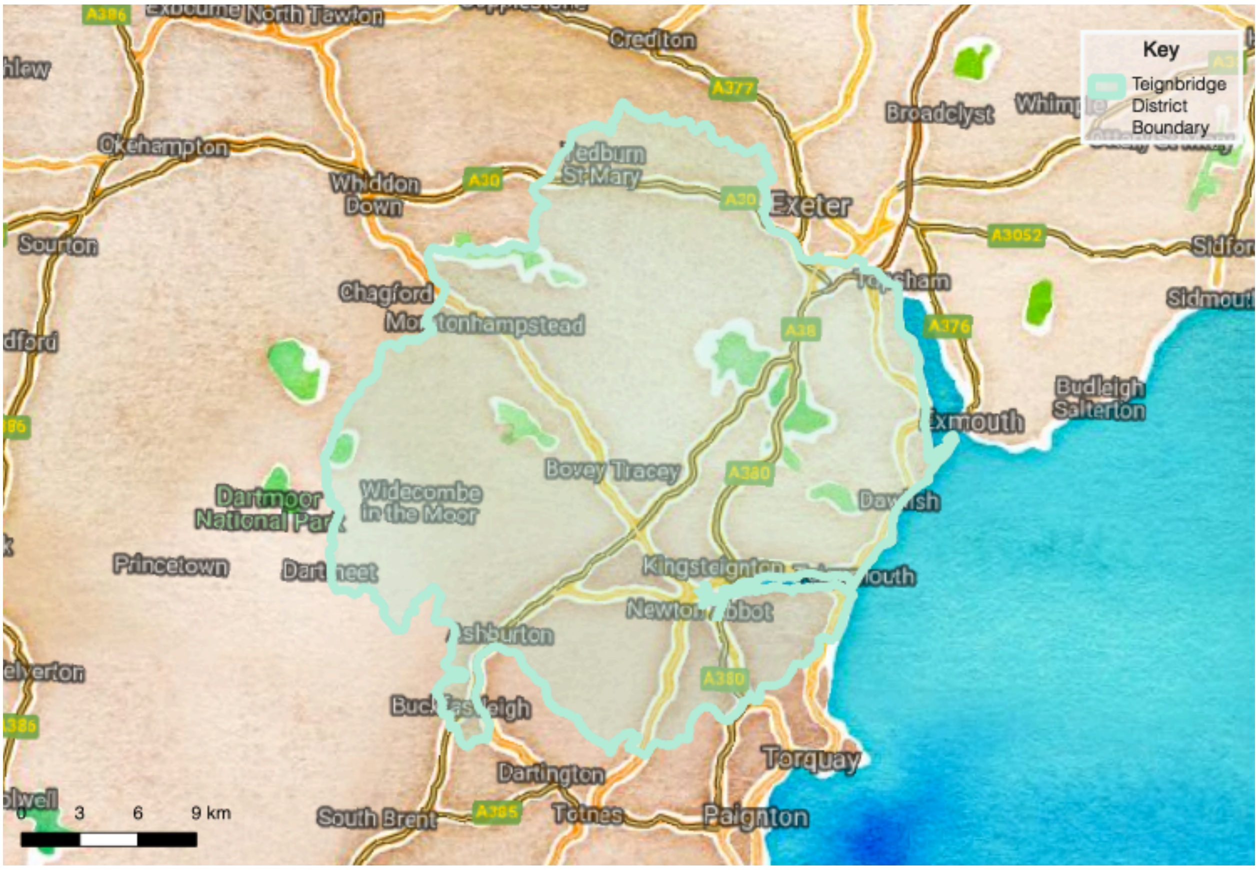

Figure 12: Teignbridge District Boundary map

In 2018, Teignbridge had a total population of 132,844[17]. A study carried out by NHS England in 2013, stated the population profile of the District is comparable with the County of Devon as a whole. It anticipates that the ageing population will continue to rise in subsequent years (with the time lapsed between the NHS study and this report, it can be assumed that this increase may have already impacted upon the population balance). Healthy, active lifestyles and benefits with regards to more than 20 health conditions or diseases are specifically highlighted. Physical activity was highest in rural parts of the Local Authority, with lower levels in towns such as Teignmouth and Dawlish (It is important to note that, the study does exclude areas of Dartmoor National Park which lie within the Teignbridge District Boundary)[18].

The ORVal tool, is an online application which has been "developed as a collaboration between the Land, Environment, Economics and Policy (LEEP) Institute at the University of Exeter and DEFRA". The tool aims to provide information which can enable benefits derived from accessible green space in England and Wales to be interpreted and analysed. This data can be explored in further detail using the mapping tool, available at: http://leep.exeter.ac.uk/orval. Estimations of the

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[16] Teignbridge, 2019

[17] LGA, anon

[18] NHS, 2012

number of visits and the welfare value are "*derived from a statistical model of recreational demand*"[19].

The term 'welfare' refers to "*the sense of well-being or utility that an individual feels from their experiences.*" The tool assumes that when someone visits a green space, the welfare exceeds that of other activities, such as, watching television. Estimations of which green spaces an individual might visit are involved in the calculation of annual welfare values by the tool.

Socioeconomic characteristics, location of residence, day of the week and month of the year, in addition to site specific conditions and qualities are accommodated within the modelling[15]. Travel costs and duration are based upon a value of 25p per km and Department for Transport time estimations[15].

Estimated Visitation

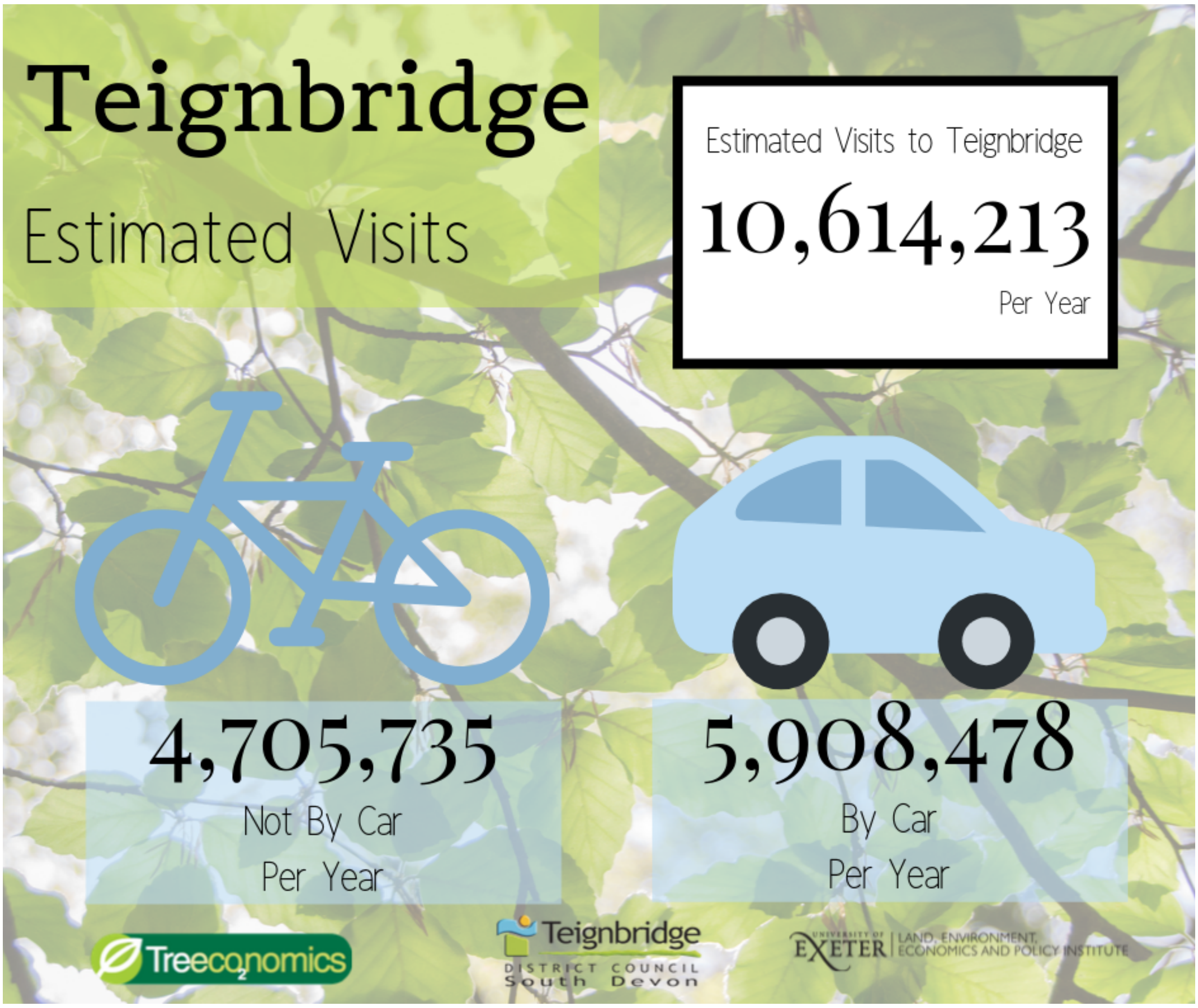

Figure 13: Infographic displaying estimated number of visits to Teignbridge (per year) by car and not by car

Teignbridge is visited over 10 Million times annually by residents and visitors. As illustrated in Figure 13, more visitors travel to the district by car than not by car. Examining visitation to Teignbridge using four social grades gives an overview of the socioeconomic value. ORVal uses

[19] Day *et al, 2018*

the ONS grading system, as detailed by both IPSOS and the National Readership Survey (NRS) to disaggregate the data.

The four social grades include AB, C1, C2 and DE, these codes are based on the NRS System (National Readership Survey), which has since been updated by The Office for National Statistics (ONS) in 2001. This system uses a numerical category system. Using a conversion, it can be said that the AB group includes individuals who hold a professional, managerial position, C1 refers to professional roles and some small employers. Lower level supervisors and technical roles fall into the C2 category whereas semi/ unskilled manual positions fall into the DE category alongside those who are unemployed[20].

It is interesting to note that individuals holding professional roles or working as small-scale employers (C1 Social Category) make more visits to Teignbridge than any other group (3,384,858). This is in contrast to a similar study of Hyde Park in London. The Hyde Park study identified the AB social category (professional, managerial positions) made the greatest number of visits. Within Teignbridge, individuals who are unemployed or hold semi/unskilled manual positions (DE) made the lowest number of visits (1,855,421). Given the location of recreational sites within the district this could perhaps be explained by the amount of travel required to access green spaces. Individuals within this category may not have access to personal transportation and may rely on public transport networks. To support this theory the NHS England study (discussed earlier) found that levels of activity were highest in rural areas, and lower within the larger town settlements. State pensioners and individuals who are unemployed may generally live more centrally within the larger towns, and therefore have a lower level of physical activity, leading to these lower numbers of visitation to Teignbridge's green spaces.

[20] ONS, 2001

Welfare Value

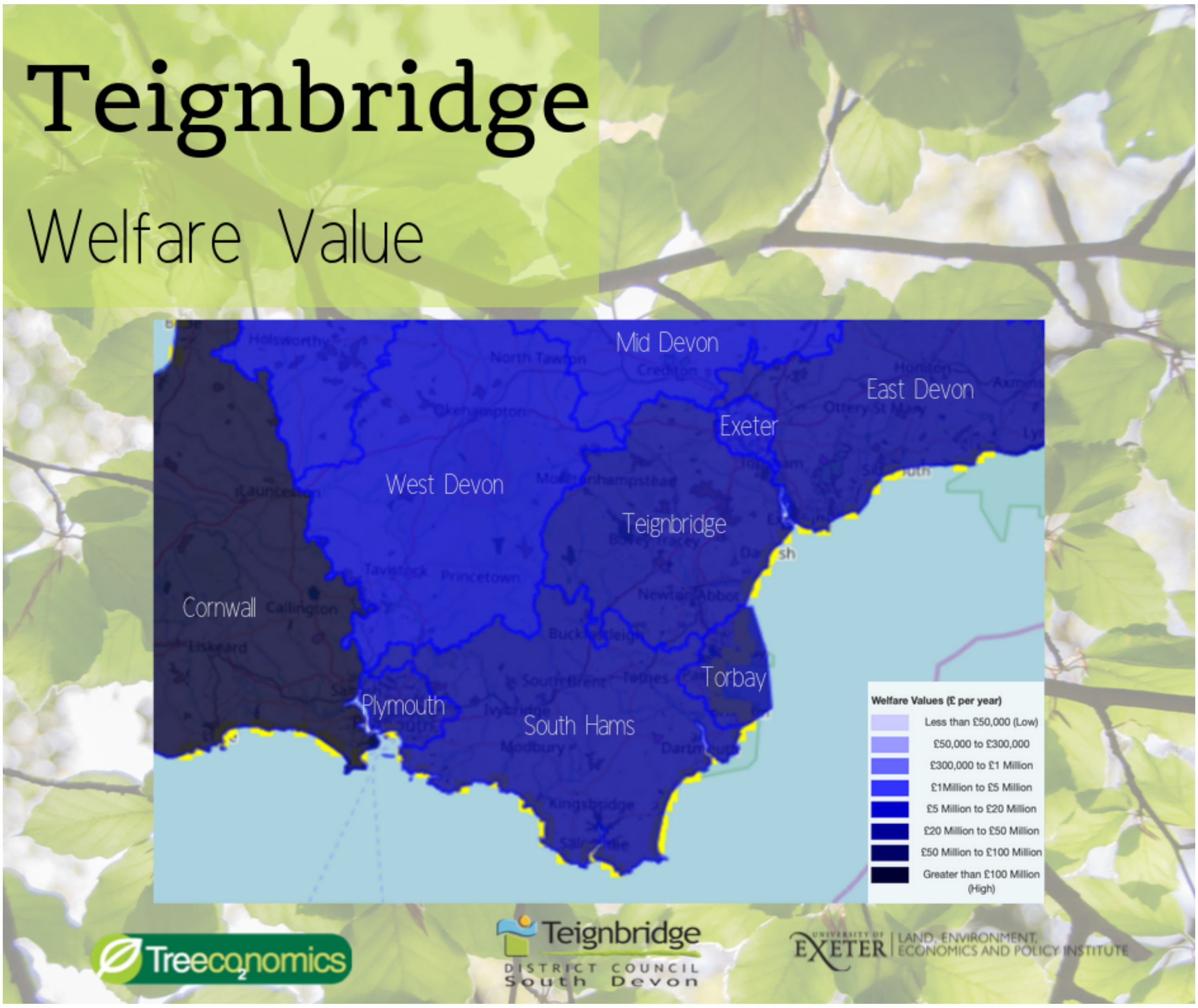

Figure 14: The Welfare Value of Local Authorities within Devon County

As can be seen from Figure 14, Teignbridge District falls within the £20-50 Million Welfare Value Category, alongside other Local Authorities. The Welfare Value for Teignbridge stands at £38,847,646 annually, this exceeds both East Devon, located to the North East, and the South Hams, located to the South East, who have values of £38,464,600 and £38,316,197 respectively.

Figure 16: Infographic illustrating the the value of recreational sites managed by Teignbridge District Council.

The three larger towns within the Teignbridge District are Teignmouth, Dawlish and Newton Abbott. Figure 16 above, illustrates the welfare value of green spaces from each town. Looking at the three sites featured in Figure 16, it can be said that the Socio Economic Welfare Value data reflects that of Teignbridge as a whole. The C1 category has the highest value for all three sites and DE has the lowest with AB in second and C2 in third position.

The ORVal tool estimates the award winning[21] Decoy Country Park has one of the highest Welfare Values at £900,313 when compared with other green spaces managed by Teignbridge District Council. Decoy Park has an outstanding amenity value for local communities. The formal playing playing fields provide space for sport and physical activity, additionally, the lake hosts water sport recreation. The local nature reserve encourages wildlife watching, walking and peaceful rural activities. Children can access the water play feature, the woodland trim trail and large play area. This Country Park is a valuable green space for local residents and those visiting the district as reflected by the welfare value.

Eastcliff/ Mules Park is an 8.3ha coastal green space located within the main town centre of Teignmouth. This green space expands across cliffs and alongside the railway and has a value of £122,022. The peace and tranquility of Eastcliff Park is enhanced by it's historical presence, sub-tropical garden, ponds and open grassland[22].

[21] Teignbridge District Council, 2018

Dawlish Warren is a coastal space with large dunes rolling inland from the beach. It is an outstanding nature reserve and provides a unique habitat for a range of species. It's beauty attracts many visitors, including large numbers of tourists from outside of the county. Dawlish Warren's iconic groin structures, (as seen in Figure 16) are characteristic of this coastal destination as a result of physical environmental factors. To enhance protection from storm waves, The Environment Agency have published their proposal for new flood defences, a beach re-charge scheme (additional sand loading), and improvements to the seawall and groins[22].

Figure 15: Infographic to show the welfare value of Teignbridge and its highest social group

Across all recreational sites within Teignbridge, the ORVal tool estimates that, in addition to having the highest number of visits, professional/small scale employers (C1) also have the highest Welfare Value, around 40% greater than the those who are unemployed/work in unskilled manual roles (DE). The Welfare Value for the C1 Social Category stands at £12,428,716 in comparison with the DE Category at just £5,577,432.

A study which examined 'Perceived Neighbourhood Environment and Park Use as Mediators of the Effect of Area Socio-Economic Status on Walking Behaviours' similarly concluded that individuals with a higher socio-economic position within the community had a higher frequency of local park use. Their study concluded that this social group reported higher levels of security, maintenance and aesthetic qualities which encouraged socialising and reduced antisocial behaviours. To support this finding it also stated that residents with a higher socio economics

[22] Environment Agency, 2017

position reported "*an average 22% more weekly minutes of recreational walking*" than those in a lower position.[23]

Unemployed/ individuals working in unskilled manual labour roles have the lowest welfare value within Teignbridge (£6,851,284). Individuals with Professional/ managerial roles hold a value of £10,653,391 which is £1,775,325 less than the C1 group who have the highest welfare value within Teignbridge.

[23] Leslie, E. *et al*, 2010

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 threats like Ash dieback.
- Data can be used to produce educational literature and informative features about Teignbridge's trees (e.g. Tree tags highlighting the benefits of urban trees).
- Using the data for cost benefit analysis to inform decision making.
- 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 Teignbridge's tree management plan.
- Inform species selection. 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 this report together with an ancient tree management plan to include non-natives and heritage trees to broaden the potential for Teignbridge's trees to build resilience to future change.

Conclusions

The tree population within Teignbridge's council managed tree inventory generally has a good species and age diversity. It is acknowledged that there are a number of constraints on highways planting, however that can hinder planting of larger-growing species[24]. Additional larger-growing species provide some resilience from possible future influences such as climate change and pest and disease outbreaks. The role of Teignbridge's trees in complementing people's health is clear, through air pollution removal especially. Teignbridge's public trees provide a valuable benefit of over £22,370 in ecosystem services each year.

In terms of structural diversity the English oak (*Quercus robur*) have the largest proportion of trees in the larger size classes, over time other tree species such as Sycamore (*Acer* pseudoplatanus) and Norway maple (*Acer platanoides*) may develop into large specimens and improve the structural diversity within Teignbridge. Larger trees are important because they provide greater canopy cover and ecosystem service provision. They also tend to have higher amenity value than their smaller counterparts.

Teignbridge's tree inventory is constituted by a large proportion of *English oak* (*Quercus robur*) and is therefore quite dependant on this species for the delivery of ecosystem services (11.5% of population, 17.9% of leaf area and 29.5% of all carbon stored in the trees). Teignbridge council would benefit from having a greater proportion of larger trees, of a more diverse range of 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 Teignbridge because only a proportion of the trees were considered and 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. Targets to increase canopy cover, protect large and veteran trees, plant large trees where possible, diversify the urban forest and plant climate adaptable species should also be incorporated into the strategic documents for Teignbridge's management.

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. New tree planting can contribute to the growth of canopy cover. However the most effective strategy for increasing average tree size and the extent of tree canopy is to 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 Teignbridge in a variety of ways and there are great uncertainties about how this may manifest. Some species may be less able to survive under new climatic conditions. New conditions may also allow different pests and diseases to become prevalent. Further studies into this area would be useful in informing any long term tree strategies or Urban Forest Masterplans.

The ORVal tool estimates that over 10,000,000 visits are made to Teignbridge every year. This Local Authority, popular with tourists, has a varied landscape and range of recreational green spaces. The welfare value of the Teignbridge District stands at £38,847,646. Individuals who hold managerial or professional roles (within the C1 socio-economic category) make the most visits and have the highest welfare value. Those who are unemployed or work in unskilled/ semi-skilled manual roles have the lowest (the DE social category). Teignbridge is accessed by individuals who travel by car more than those who travel on foot/ by public transport. With such a focus on

[24] https://www.legislation.gov.uk/ukpga/1980/66

the current climatic situation, it would be recommended that further studies look into improving access, and encouraging more travel by public transport to these beautiful sites. Teignbridge is of huge value to the local and visiting community and it would be interesting to explore the data further to give a detailed view of the benefits provided by these outstanding green spaces.

The challenge now is to ensure that policy makers and practitioners take full account of Teignbridge'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.

Appendix I. Relative Tree Effects

The trees in Teignbridge's tree inventory provide benefits that include carbon storage and sequestration and air pollution 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 4,190 family cars
- Annual C emissions from 1,720 single-family houses

Nitrogen dioxide removal is equivalent to:

- Annual nitrogen dioxide emissions from 9 family cars
- Annual nitrogen dioxide emissions from 4 single-family houses

Sulphur dioxide removal is equivalent to:

- Annual sulphur dioxide emissions from 1,140 family cars
- Annual sulphur dioxide emissions from 3 single-family houses

Oxygen production is equivalent to:

- Annual Oxygen intake from 944 people.

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 Dominance - Ranking List

Dominance value is based on the combination of leaf area and tree population and gives a much better idea of the tree species dominance in the landscape than on tree numbers or leaf area alone.

Species	Percent Population	Percent Leaf Area	Dominance Value
Quercus robur	11.50	17.90	29.40
Fraxinus excelsior	8.30	7.00	15.20
Fagus sylvatica	4.20	9.60	13.80
Acer pseudoplatanus	5.90	7.90	13.80
Acer platanoides	4.30	5.20	9.50
Tilia x europaea	3.30	5.10	8.40
Betula pendula	4.90	2.60	7.50
Castanea sativa	2.90	4.20	7.10
Quercus/live ilex	2.70	3.20	5.90
Acer campestre	2.40	2.20	4.60
Aesculus hippocastanum	1.60	2.90	4.50
Pinus sylvestris	1.90	1.60	3.50
Crataegus mollis	3.10	0.40	3.50
Taxus baccata	1.40	1.80	3.20
Sorbus aucuparia	2.60	0.60	3.10
Prunus	1.90	0.90	2.70
Platanus x acerifolia	1.10	1.60	2.60
Prunus avium	1.60	1.00	2.60
Ulmus procera	1.40	1.00	2.40
Pinus radiata	1.10	1.10	2.20
Sorbus aria	1.50	0.60	2.10
Pinus nigra	1.30	0.80	2.00
Alnus glutinosa	1.10	0.80	1.90
Taxus baccata 'fastigiata'	1.10	0.70	1.80
Corylus avellana	1.10	0.70	1.80
Quercus cerris	0.70	0.90	1.60
Ilex aquifolium	1.10	0.40	1.50
Quercus x hispanica	0.40	0.90	1.40
Alnus cordata	0.80	0.60	1.30
Ulmus	0.70	0.60	1.30
Acer	0.70	0.60	1.30
Cordyline australis	0.70	0.60	1.30

Species	Percent Population	Percent Leaf Area	Dominance Value
Tilia cordata	0.60	0.70	1.20
Quercus rubra	0.60	0.60	1.20
Chamaecyparis lawsoniana	0.80	0.50	1.20
Carpinus betulus	0.70	0.50	1.20
Cupressus macrocarpa	0.60	0.50	1.10
Cornus	0.70	0.30	1.00
Malus	0.80	0.20	1.00
Sorbus	0.70	0.20	1.00
Salix alba	0.50	0.40	0.90
Salix caprea	0.60	0.30	0.90
Salix nigra	0.70	0.20	0.90
Tilia	0.40	0.50	0.80
Salix	0.40	0.40	0.80
Populus nigra	0.50	0.30	0.80
Prunus Kanzan	0.50	0.30	0.80
Populus	0.30	0.40	0.70
Ulmus x hollandica	0.50	0.30	0.70
Prunus cerasifera	0.50	0.20	0.70
Ulmus glabra	0.30	0.30	0.60
Cedrus atlantica	0.30	0.30	0.60
Cupressocyparis leylandii	0.40	0.20	0.60
Acer saccharinum	0.20	0.30	0.50
Robinia pseudoacacia	0.20	0.20	0.50
Quercus petraea	0.20	0.30	0.40
Sequoiadendron giganteum	0.20	0.30	0.40
Tilia platyphyllos	0.20	0.30	0.40
Liriodendron tulipifera	0.20	0.30	0.40
Alnus incana	0.20	0.20	0.40
Prunus americana	0.30	0.10	0.40
Cedrus deodara	0.20	0.10	0.40
Larix decidua	0.20	0.20	0.30
Juglans regia	0.20	0.20	0.30
Metasequoia glyptostroboides	0.20	0.20	0.30
Ailanthus altissima	0.10	0.20	0.30
Fagus	0.10	0.20	0.30

Species	Percent Population	Percent Leaf Area	Dominance Value
Pseudotsuga menziesii	0.10	0.20	0.30
Aesculus x carnea	0.10	0.20	0.30
Cupressus	0.30	0.10	0.30
Quercus coccinea	0.20	0.10	0.30
Prunus padus	0.20	0.10	0.30
Prunus serrula	0.20	0.10	0.30
Thuja plicata	0.20	0.10	0.30
Corylus	0.20	0.10	0.30
Chamaecyparis	0.20	0.10	0.30
Liquidambar styraciflua	0.20	0.10	0.30
Betula x jackii	0.20	0.10	0.20
Fraxinus	0.10	0.10	0.20
Quercus	0.10	0.10	0.20
Fraxinus oxycarpa	0.10	0.10	0.20
Eucalyptus gunnii	0.10	0.10	0.20
Cedrus libani	0.10	0.10	0.20
Fraxinus ornus	0.10	0.10	0.20
Sequoia sempervirens	0.10	0.10	0.20
Picea	0.10	0.10	0.20
Populus alba	0.10	0.10	0.20
Picea abies	0.10	0.10	0.20
Crataegus pruinosa	0.20	<0.10	0.20
Crataegus monogyna	0.20	<0.10	0.20
Trachycarpus fortunei	0.20	<0.10	0.20
Laurus nobilis	0.20	<0.10	0.20
Prunus spinosa	0.10	<0.10	0.20
Pyrus calleryana 'Chanticleer'	0.10	<0.10	0.20
Juglans nigra	<0.10	0.10	0.10
Araucaria araucana	<0.10	0.10	0.10
Crataegus crus-galli	0.10	<0.10	0.10
Prunus laurocerasus	0.10	<0.10	0.10
Laburnum anagyroides	0.10	<0.10	0.10
Prunus subhirtella	0.10	<0.10	0.10
Magnolia grandiflora	0.10	<0.10	0.10
Ginkgo biloba	0.10	<0.10	0.10

Species	Percent Population	Percent Leaf Area	Dominance Value
Amelanchier laevis	0.10	<0.10	0.10
Crataegus	0.10	<0.10	0.10
Prunus lusitanica	0.10	<0.10	0.10
Sorbus intermedia	0.10	<0.10	0.10
Pyrus salicifolia	0.10	<0.10	0.10
Magnolia	0.10	<0.10	0.10
Acer davidii	0.10	<0.10	0.10
Sophora japonica	0.10	<0.10	0.10
Malus John Downie	0.10	<0.10	0.10
Aesculus indica	0.10	<0.10	0.10
Betula	0.10	<0.10	0.10
Pistacia mexicana	0.10	<0.10	0.10
Viburnum opulus	0.10	<0.10	0.10
Tilia cordata 'Greenspire'	0.10	<0.10	0.10
Prunus sargentii	0.10	<0.10	0.10
Malus sylvestris	0.10	<0.10	0.10
Aesculus	<0.10	<0.10	0.10
Cercidiphyllum japonicum	<0.10	<0.10	0.10
Prunus x shirotae	<0.10	<0.10	0.10
Acer rubrum	<0.10	<0.10	0.10
Tilia petiolaris	<0.10	<0.10	0.10
Larix kaempferi	<0.10	<0.10	0.10
Acer negundo	<0.10	<0.10	0.10
Acer palmatum	<0.10	<0.10	0.10
Arbutus unedo	<0.10	<0.10	0.10
Prunus x hiliieri	<0.10	<0.10	0.10
Quercus frainetto	<0.10	<0.10	0.10
Abies	<0.10	<0.10	<0.10
Chamaecyparis pisifera	<0.10	<0.10	<0.10
Quercus/live suber	<0.10	<0.10	<0.10
Betula utilis	<0.10	<0.10	<0.10
Mespilus germanica	<0.10	<0.10	<0.10
Cercis siliquastrum	<0.10	<0.10	<0.10
Platanus orientalis	<0.10	<0.10	<0.10
Sorbus domestica	<0.10	<0.10	<0.10

Species	Percent Population	Percent Leaf Area	Dominance Value
Quercus palustris	<0.10	<0.10	<0.10
Buxus sempervirens	<0.10	<0.10	<0.10
Laurus	<0.10	<0.10	<0.10
Malus tschonoskii	<0.10	<0.10	<0.10
Salix x sepulcralis	<0.10	<0.10	<0.10
Pyrus communis	<0.10	<0.10	<0.10
Populus trichocarpa	<0.10	<0.10	<0.10
Cupania glabra	<0.10	<0.10	<0.10
Syringa vulgaris	<0.10	<0.10	<0.10
Tilia tomentosa	<0.10	<0.10	<0.10
Corymbia confertiflora	<0.10	<0.10	<0.10
Juniperus communis	<0.10	<0.10	<0.10
Populus balsamifera	<0.10	<0.10	<0.10
Nothofagus obliqua	<0.10	<0.10	<0.10
Nothofagus antarctica	<0.10	<0.10	<0.10
Ligustrum vulgare	<0.10	<0.10	<0.10
Aesculus parviflora	<0.10	<0.10	<0.10
Calocedrus decurrens	<0.10	<0.10	<0.10
Pinus washoensis	<0.10	<0.10	<0.10
Morus alba	<0.10	<0.10	<0.10
Cryptomeria japonica	<0.10	<0.10	<0.10
Nothofagus	<0.10	<0.10	<0.10
Ilex	<0.10	<0.10	<0.10
Planchonella	<0.10	<0.10	<0.10
Eucalyptus conferruminata	<0.10	<0.10	<0.10
Betula costata	<0.10	<0.10	<0.10
Betula nigra	<0.10	<0.10	<0.10
Koelreuteria paniculata	<0.10	<0.10	<0.10
Paulownia tomentosa	<0.10	<0.10	<0.10
Populus x canescens	<0.10	<0.10	<0.10
Prunus dulcis	<0.10	<0.10	<0.10
Parrotia persica	<0.10	<0.10	<0.10
Malus baccata v purpurea	<0.10	<0.10	<0.10
Cupressus funebris	<0.10	<0.10	<0.10
Thujopsis dolabrata	<0.10	<0.10	<0.10

Species	Percent Population	Percent Leaf Area	Dominance Value
Pyrus	<0.10	<0.10	<0.10
Malus floribunda	<0.10	<0.10	<0.10
Malus x purpurea	<0.10	<0.10	<0.10
Chamaecyparis nootkatensis	<0.10	<0.10	<0.10
Davidia involucrata	<0.10	<0.10	<0.10
Picea sitchensis	<0.10	<0.10	<0.10
Rhus hirta	<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 (£)
Quercus robur	802	1585.20	24.04	663.87	0.23	£3,812,099
Fagus sylvatica	294	479.90	7.67	356.71	0.13	£1,238,029
Tilia x europaea	229	198.60	3.45	190.11	0.07	£936,373
Acer pseudoplatanus	414	294.20	6.32	291.04	0.10	£899,655
Fraxinus excelsior	578	237.00	5.60	257.73	0.09	£859,162
Quercus ilex	191	290.50	4.27	117.49	0.04	£703,702
Castanea sativa	206	206.50	4.20	155.62	0.05	£631,889
Pinus radiata	76	101.80	1.02	41.18	0.01	£501,587
Acer platanoides	300	142.50	3.74	193.78	0.07	£464,456
Aesculus hippocastanum	114	243.30	3.50	106.53	0.04	£442,855
Taxus baccata	96	78.30	1.12	68.34	0.02	£422,779
Betula pendula	345	131.90	4.39	94.56	0.03	£376,072
Pinus sylvestris	134	56.10	1.15	57.73	0.02	£341,947
Pinus nigra	88	35.10	0.68	28.52	0.01	£285,692
Quercus x hispanica	31	116.90	1.52	34.50	0.01	£272,929
Quercus cerris	49	79.50	1.33	33.55	0.01	£196,158
Cupressus macrocarpa	39	47.90	0.60	18.37	0.01	£185,848
Prunus avium	113	67.20	1.65	36.94	0.01	£180,512
Acer campestre	165	56.80	1.68	82.16	0.03	£169,845
Taxus baccata 'fastigiata'	77	30.70	0.43	25.82	0.01	£139,427
Platanus x acerifolia	75	40.60	0.99	58.19	0.02	£128,581
Sequoiadendron giganteum	11	39.40	0.28	10.73	<0.01	£124,661
Tilia cordata	40	24.30	0.49	24.66	0.01	£122,622
Quercus rubra	39	34.00	0.78	23.37	0.01	£100,840
Cedrus atlantica	21	19.10	0.24	10.20	<0.01	£99,283
Alnus glutinosa	75	30.40	0.90	29.14	0.01	£95,565
Chamaecyparis lawsoniana	54	23.30	0.40	17.07	0.01	£95,376
Salix	31	33.70	0.46	13.12	<0.01	£94,791
Corylus avellana	77	28.00	0.81	25.11	0.01	£90,031
Populus	22	27.50	0.50	14.94	0.01	£87,349
Salix alba	34	26.30	0.57	14.22	<0.01	£83,919

Species	Trees	Carbon Storage (Tonnes)	Gross Carbon Seq (Tonnes/ Yr)	Avoided Runoff (m^3/Yr)	Pollution Removal (Tonne/ Yr)	Replacement Cost (£)
Alnus cordata	53	25.10	0.68	20.41	0.01	£82,329
Ilex aquifolium	77	22.60	0.73	13.41	<0.01	£74,096
Acer	46	23.70	0.56	23.41	0.01	£74,069
Carpinus betulus	50	23.50	0.58	17.33	0.01	£73,906
Sorbus aria	105	21.70	0.78	23.06	0.01	£72,320
Prunus	130	27.70	1.14	32.59	0.01	£70,299
Populus nigra	34	18.70	0.39	12.52	<0.01	£68,449
Cordyline australis	47	2.60	0.02	21.53	0.01	£64,768
Tilia	26	10.60	0.28	16.99	0.01	£57,224
Quercus petraea	13	21.60	0.42	9.73	<0.01	£56,205
Cedrus deodara	16	11.00	0.14	5.50	<0.01	£55,975
Cedrus libani	6	10.80	0.10	4.17	<0.01	£52,172
Crataegus mollis	214	16.00	0.91	15.40	0.01	£48,954
Acer saccharinum	13	13.20	0.22	10.52	<0.01	£47,436
Fagus	5	16.90	0.23	8.50	<0.01	£42,693
Robinia pseudoacacia	17	14.50	0.28	8.13	<0.01	£41,985
Salix caprea	40	13.60	0.38	10.63	<0.01	£40,949
Tilia platyphyllos	13	7.10	0.15	9.27	<0.01	£36,602
Sorbus aucuparia	180	11.40	0.69	20.96	0.01	£35,342
Ailanthus altissima	10	11.40	0.23	5.93	<0.01	£32,352
Pseudotsuga menziesii	7	5.80	0.08	7.22	<0.01	£31,455
Metasequoia glyptostroboides	12	6.40	0.10	5.81	<0.01	£29,916
Cupressocyparis leylandii	31	6.20	0.16	7.23	<0.01	£29,672
Alnus incana	17	9.00	0.24	7.25	<0.01	£29,603
Ulmus procera	100	17.10	0.66	37.45	0.01	£28,378
Thuja plicata	16	2.90	0.05	3.57	<0.01	£27,477
Cupressus	18	5.80	0.13	3.36	<0.01	£27,425
Aesculus x carnea	8	7.80	0.16	6.16	<0.01	£23,444
Prunus Kanzan	35	9.60	0.35	9.70	<0.01	£22,716
Liriodendron tulipifera	11	6.50	0.14	9.25	<0.01	£22,011
Quercus coccinea	14	6.50	0.19	5.31	<0.01	£19,498
Ulmus	51	11.00	0.39	22.64	0.01	£19,234
Sequoia sempervirens	5	3.60	0.06	4.18	<0.01	£16,939

Species	Trees	Carbon Storage (Tonnes)	Gross Carbon Seq (Tonnes/ Yr)	Avoided Runoff (m^3/Yr)	Pollution Removal (Tonne/ Yr)	Replacement Cost (£)
Picea	5	4.50	0.08	4.10	<0.01	£16,897
Prunus padus	14	5.50	0.18	4.98	<0.01	£16,506
Quercus	9	6.80	0.14	3.50	<0.01	£16,231
Sorbus	52	5.20	0.26	7.91	<0.01	£15,903
Chamaecyparis	13	3.50	0.08	3.34	<0.01	£15,673
Prunus cerasifera	33	7.50	0.29	8.32	<0.01	£15,151
Populus alba	7	3.80	0.09	2.95	<0.01	£14,901
Cornus	50	6.50	0.33	11.51	<0.01	£14,286
Malus	55	3.80	0.22	6.89	<0.01	£13,997
Araucaria araucana	2	2.20	0.03	2.04	<0.01	£13,253
Amelanchier laevis	6	3.70	0.07	0.98	<0.01	£10,820
Eucalyptus gunnii	6	5.50	0.11	4.32	<0.01	£10,795
Fraxinus	10	2.70	0.08	3.63	<0.01	£10,421
Salix nigra	50	3.50	0.22	6.89	<0.01	£10,244
Prunus americana	18	4.00	0.17	4.93	<0.01	£10,168
Prunus serrula	15	3.80	0.15	4.28	<0.01	£10,084
Quercus/live suber	1	4.50	0.06	1.25	<0.01	£9,895
Corylus	14	3.00	0.12	4.55	<0.01	£9,679
Juglans regia	11	2.90	0.11	6.64	<0.01	£9,430
Betula x jackii	11	3.40	0.11	3.05	<0.01	£9,251
Prunus lusitanica	4	3.20	0.08	1.67	<0.01	£8,755
Picea abies	5	3.00	0.06	3.58	<0.01	£8,659
Larix decidua	11	3.20	0.08	6.69	<0.01	£7,956
Ulmus glabra	23	4.70	0.17	9.67	<0.01	£7,912
Cercidiphyllum japonicum	2	2.50	0.05	1.79	<0.01	£6,903
Fraxinus ornus	8	1.80	0.06	2.90	<0.01	£6,577
Ulmus x hollandica	33	4.00	0.18	9.76	<0.01	£6,551
Fraxinus oxycarpa	10	1.80	0.07	2.94	<0.01	£6,417
Liquidambar styraciflua	13	2.00	0.06	2.83	<0.01	£5,951
Salix x sepulcralis	1	1.90	0.03	0.72	<0.01	£5,942
Ginkgo biloba	5	1.80	0.05	1.66	<0.01	£5,203
Acer rubrum	2	1.40	0.04	1.34	<0.01	£4,671
Prunus x shirotae	3	1.70	0.05	1.20	<0.01	£4,553

Species	Trees	Carbon Storage (Tonnes)	Gross Carbon Seq (Tonnes/Yr)	Avoided Runoff (m^3/Yr)	Pollution Removal (Tonne/Yr)	Replacement Cost (£)
Populus balsamifera	1	0.90	0.02	0.51	<0.01	£4,153
Magnolia grandiflora	5	1.10	0.04	1.71	<0.01	£3,679
Chamaecyparis pisifera	2	0.70	0.02	0.74	<0.01	£3,269
Juglans nigra	3	0.90	0.03	2.30	<0.01	£3,024
Prunus laurocerasus	6	1.00	0.05	1.49	<0.01	£2,905
Prunus spinosa	10	1.00	0.06	1.64	<0.01	£2,902
Arbutus unedo	3	0.80	0.03	0.46	<0.01	£2,719
Acer davidii	4	0.80	0.03	1.32	<0.01	£2,602
Pistacia mexicana	5	0.90	0.04	0.29	<0.01	£2,580
Prunus subhirtella	6	1.00	0.05	1.29	<0.01	£2,526
Quercus frainetto	2	0.80	0.03	0.89	<0.01	£2,430
Trachycarpus fortunei	13	<0.10	<0.01	0.74	<0.01	£2,333
Laurus nobilis	11	0.90	0.05	1.69	<0.01	£2,308
Platanus orientalis	1	0.60	0.02	0.95	<0.01	£2,197
Betula	4	0.70	0.03	0.95	<0.01	£2,142
Crataegus monogyna	13	0.90	0.06	1.10	<0.01	£2,110
Laburnum anagyroides	6	0.80	0.04	1.42	<0.01	£2,045
Sorbus intermedia	5	0.60	0.03	0.94	<0.01	£1,907
Crataegus pruinosa	14	0.80	0.06	0.99	<0.01	£1,837
Sophora japonica	5	0.60	0.02	0.68	<0.01	£1,819
Abies	2	0.40	0.01	0.75	<0.01	£1,571
Calocedrus decurrens	1	0.30	0.01	0.33	<0.01	£1,505
Cupania glabra	1	0.50	0.02	0.62	<0.01	£1,496
Tilia tomentosa	1	0.30	0.01	0.57	<0.01	£1,476
Ilex	1	0.40	0.01	0.27	<0.01	£1,476
Tilia petiolaris	3	0.30	0.01	0.72	<0.01	£1,395
Crataegus	7	0.40	0.03	0.44	<0.01	£1,392
Larix kaempferi	2	0.50	0.01	1.20	<0.01	£1,348
Aesculus	3	0.50	0.02	1.27	<0.01	£1,341
Cercis siliquastrum	2	0.40	0.02	0.57	<0.01	£1,315
Prunus sargentii	4	0.50	0.02	0.66	<0.01	£1,263
Pinus washoensis	1	0.20	0.01	0.32	<0.01	£1,204
Betula utilis	2	0.40	0.02	0.63	<0.01	£1,140

Species	Trees	Carbon Storage (Tonnes)	Gross Carbon Seq (Tonnes/ Yr)	Avoided Runoff (m^3/Yr)	Pollution Removal (Tonne/ Yr)	Replacement Cost (£)
Paulownia tomentosa	1	0.30	0.01	0.23	<0.01	£1,085
Malus John Downie	5	0.30	0.02	0.58	<0.01	£982
Acer palmatum	3	0.30	0.01	0.53	<0.01	£964
Pyrus calleryana 'Chanticleer'	10	0.30	0.03	0.45	<0.01	£957
Buxus sempervirens	2	0.30	0.01	0.33	<0.01	£937
Sorbus domestica	2	0.30	0.01	0.39	<0.01	£882
Pyrus salicifolia	6	0.30	0.02	0.41	<0.01	£853
Crataegus crus-galli	8	0.40	0.03	0.54	<0.01	£823
Juniperus communis	1	0.20	0.01	0.54	<0.01	£805
Quercus palustris	2	0.20	0.01	0.35	<0.01	£670
Magnolia	5	0.30	0.02	0.93	<0.01	£649
Acer negundo	3	0.30	0.02	0.63	<0.01	£645
Eucalyptus conferruminata	1	0.20	0.01	0.25	<0.01	£595
Populus x canescens	1	0.10	0.01	0.21	<0.01	£588
Viburnum opulus	5	0.20	0.02	0.28	<0.01	£548
Laurus	2	0.20	0.01	0.33	<0.01	£541
Cryptomeria japonica	1	0.10	<0.01	0.30	<0.01	£502
Prunus x hiliieri	3	0.20	0.01	0.43	<0.01	£501
Malus sylvestris	4	0.20	0.02	0.52	<0.01	£495
Aesculus indica	4	0.20	0.02	0.98	<0.01	£481
Morus alba	1	0.10	0.01	0.31	<0.01	£428
Ligustrum vulgare	1	0.20	0.01	0.34	<0.01	£411
Tilia cordata 'Greenspire'	5	<0.10	<0.01	0.15	<0.01	£408
Nothofagus obliqua	1	0.20	0.01	0.37	<0.01	£370
Betula costata	1	0.10	0.01	0.25	<0.01	£340
Nothofagus antarctica	1	0.10	0.01	0.35	<0.01	£329
Cupressus funebris	1	0.10	<0.01	0.08	<0.01	£329
Pyrus communis	2	0.10	0.01	0.16	<0.01	£312
Betula nigra	1	0.10	0.01	0.23	<0.01	£284
Planchonella	1	0.10	0.01	0.27	<0.01	£274
Malus tschonoskii	2	0.10	0.01	0.25	<0.01	£271
Nothofagus	1	0.10	0.01	0.28	<0.01	£219
Populus trichocarpa	2	0.10	0.01	0.12	<0.01	£219

Species	Trees	Carbon Storage (Tonnes)	Gross Carbon Seq (Tonnes/ Yr)	Avoided Runoff (m^3/Yr)	Pollution Removal (Tonne/ Yr)	Replacement Cost (£)
Syringa vulgaris	2	0.10	<0.01	0.06	<0.01	£219
Koelreuteria paniculata	1	0.10	0.01	0.23	<0.01	£167
Mespilus germanica	3	<0.10	<0.01	0.07	<0.01	£161
Aesculus parviflora	1	0.10	0.01	0.33	<0.01	£157
Corymbia confertiflora	2	<0.10	<0.01	0.02	<0.01	£144
Pyrus	1	0.10	<0.01	0.08	<0.01	£137
Parrotia persica	1	0.10	<0.01	0.15	<0.01	£135
Thujopsis dolabrata	1	<0.10	<0.01	0.08	<0.01	£120
Prunus dulcis	1	0.10	0.01	0.17	<0.01	£113
Malus baccata v purpurea	1	<0.10	<0.01	0.12	<0.01	£107
Malus floribunda	1	<0.10	<0.01	0.06	<0.01	£82
Malus x purpurea	1	<0.10	<0.01	0.06	<0.01	£82
Picea sitchensis	1	<0.10	<0.01	0.03	<0.01	£82
Davidia involucrata	1	<0.10	<0.01	0.04	<0.01	£72
Rhus hirta	1	<0.10	<0.01	0.02	<0.01	£72
Chamaecyparis nootkatensis	1	<0.10	<0.01	0.06	<0.01	£70
Total	7,000	5,375.20	101.63	3,701.60	1.30	£16,069,583

Appendix IV. Notes on Methodology

Data Formatting

Tables 5 to 8 below show the list of edits and assumptions which were made for this project, to enable the maximum amount of trees to be processed.

Reason for Removal	Details	Number of records removed
No Species	There is no data in this field (a minimum requirement for iTree)	284
No DBH	There is no data in this field (a minimum requirement for iTree)	460
	NUMBER OF RECORDS IMPORTED	**7000**

Table 5: Inventory records removed for use in Eco

Reason for Edit	Details	Number of records changed
Blank Condition	For fields without a condition rating we have assumed a Fair Condition at 82%	All
Excessive DBH	For records with an unrealistic dbh we have used the tree height to proportionately calculate an average dbh	8

Table 6: Inventory records edited for use in Eco

Condition Text	i-Tree Equivalent
Good Condition	87%

Table 7: Tree condition equivalent for use in Eco

i-Tree Notes

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

- Forest structure (e.g., species composition, tree health, leaf area, etc.).
- Amount of pollution removed hourly by trees, and its associated percent air quality improvement throughout a year. Pollution removal is calculated for ozone, sulphur dioxide, nitrogen dioxide, carbon monoxide and particulate matter (<2.5 microns).
- Total carbon stored and net carbon annually sequestered by trees.
- Effects of trees on building energy use and consequent effects on carbon dioxide emissions from power plants.
- Structural value of the forest, as well as the value for air pollution removal and carbon storage and sequestration.
- Potential impact of infestations by pests, such as Asian Long-horned 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[25]. 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[26].

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[27]. 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[28] [29] that were adjusted depending on leaf

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[25] Nowak 1994

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

[27] Baldocchi 1987, 1988

[28] Bidwell and Fraser 1972

[29] Lovett 1994

phenology and leaf area. Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere[30]. 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.

For the purposes of this report produced for Teignbridge, a standardised value has been applied across all the outputs for the removal of Ozone (O_3) from the atmosphere by the inventoried trees. This is because the value fluctuates on a daily basis according to US market behaviour and the exchange rate. The value of £0.49/kg has been used as the most up-to-date value.

Replacement Costs were based on valuation procedures of the Council of Tree and Landscape Appraisers, which uses tree species, diameter, condition and location information[31] [32].

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

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30 Zinke 1967

31 Hollis, 2007

32 Rogers et al (2012)

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