DRAFT i-Tree Eco Inventory Report

PREPARED FOR:

Newcastle City Council

PREPARED BY:
James Watson -Treeconomics
Danielle Hill -Treeconomics

CHECKED BY:

Dave Hansford -Treeconomics

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Treeconomics

Executive Summary

The trees which are managed by Newcastle City Council are generally recognised and appreciated for their amenity, presence and stature in the cityscape. However, society is often unaware of the many other benefits (or ecosystem services) that trees provide to those living in our towns and cities.

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

Trees managed by the Council are a crucial part of Newcastle's urban forest. Many of the benefits that urban forest provides are offered through these trees.

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 Newcastle's publicly owned trees, a state of the art, peer reviewed software system called i-Tree Eco[4] (referred to as 'Eco' throughout the report) was used.

This is a partial analysis as not all trees or ecosystem services were quantified or valued. Therefore the figures presented in this report should be regarded as a conservative estimate.

Highlights Include:

- **Newcastle's Council-managed trees remove over 35 tonnes of air-borne pollutants each year and store nearly 191,000 tonnes of carbon.**

- **Newcastle's Council-managed trees divert an estimated 196,000 cubic meters of storm water runoff away from the local sewer systems each year. This is worth £13,000 in avoided treatment costs annually.**

- **The total structural replacement cost of all Newcastle's Council-managed trees currently stands at £142 million.**

Table 1 (below) contains the headline figures.

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1 Doick et al (2016)

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

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

4 i-Tree Eco is i-Tree is a suite of open source, peer-reviewed and continuously improved software tools developed by the USDA Forest Service and collaborators to help urban foresters and planners assess and manage urban tree populations and the benefits they can provide. i-Tree Eco is one of the tools in the i-Tree suite. It is designed to use complete or sample plot 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

Newcastle Council Tree Inventory - Headline Figures		
Total Number of Trees Measured	213,778	
Tree Canopy Cover	150.7 Hectares	
Most Common Species	Acer pseudoplatanus, Acer, Fraxinus excelsior	
Replacement Cost	£141,879,000	
Species Recorded	187	
Amounts and Values		
Carbon Storage	190,787 tonnes	£12,783,000
Pollution Removal	35.7 tonnes	£707,670
Carbon Sequestration	5,684 tonnes	£380,837
Avoided Runoff	196,472m³	£13,164,000
Total Annual Benefits	£14,252,507.00	

Table 1: Headline figures.

Notes:
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 Newcastle 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
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 for 'Transport Urban Big' and the US externality prices where UK figures are not available; £0.984 per Kg (carbon monoxide - USEC), £6.41 per Kg (ozone - USEC), £37.88 per Kg (nitrogen dioxide - UKSDC), £1.956 per Kg (sulphur dioxide - UKSDC), £104.63 per Kg (particulate matter less than 2.5 microns - UKSDC).
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 6.1.26.

Methodology

Newcastle City Council's tree inventory, exported to '.xls' format (which included 54,659 records) was reformatted and uploaded into Eco. Amongst the data collected were tree species, height and stem diameter at breast height (dbh).

The minimum data required by Eco is tree species and 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.

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

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. Several estimates had to be inputted based on the information available within the provided tree inventory.

Of the original 54,659 records, 40,946 were individual trees suitable for import. There were 612 tree group records comprising of 172,832 trees which were suitable for import. The total number of records processed were 213,778. A description of how the data was formatted is tabulated in Appendix IV.

The inventory data is processed within Eco using the in-built local pollution and climate data to provide the 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 177 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

Newcastle Council's tree inventory has a large diversity of tree species (187). However, a few species dominate (see figure 1 below). 15.4% of the 213,778 trees in the inventory are sycamore (*Acer pseudoplatanus*) and the second, third and fourth most common trees are respectively: Maple (*Acer* – with 12.6%), Ash (*Fraxinus excelsior* – with 7.7%) and Hawthorn (*Crataegus* – with 6.7%).

The large diversity of tree species (187) within the inventory leads to relatively lower percentages for the most common species observed in the chart and a relatively high percentage by comparison for the 'all other species' category (see Appendix II).

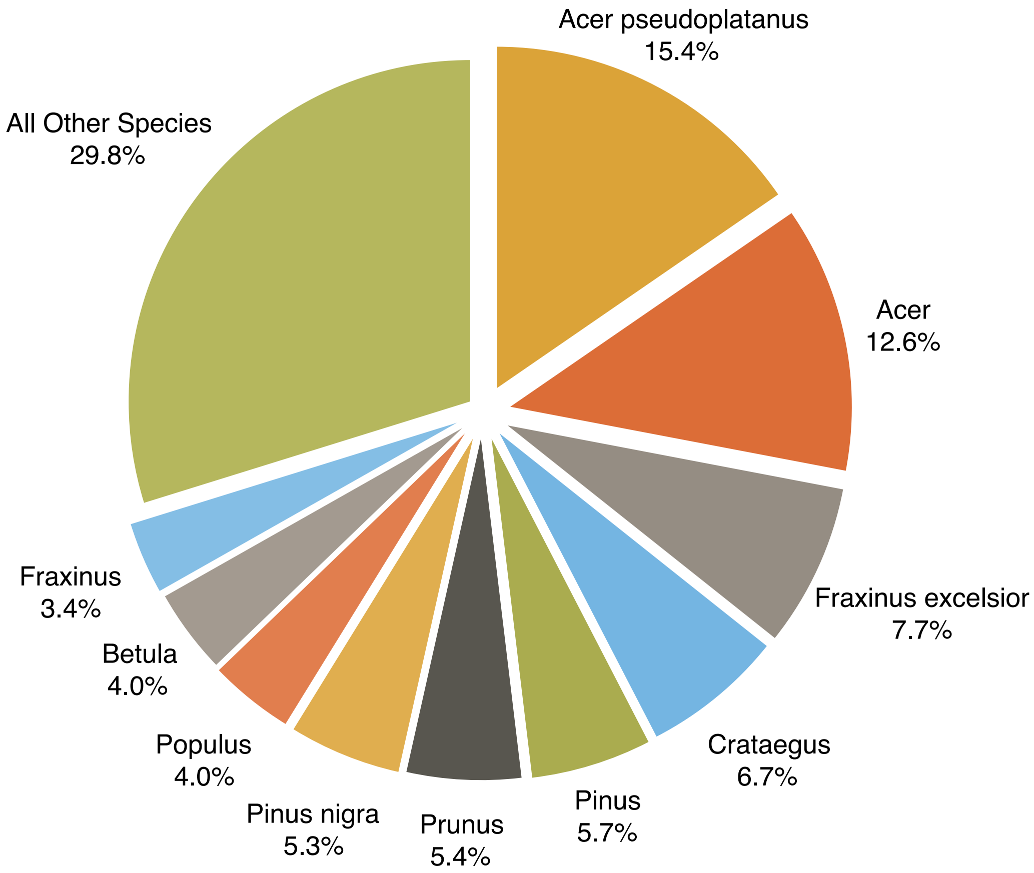

Figure 1: Percentage composition of tree species

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); *Ligustrum* (Olive family).

Trees from more distant regions may be more genetically dissimilar, with their presence in a tree population leading to increased resilience to environmental perturbations. 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 large numbers of trees will be vulnerable to a particular threat is lower, and therefore a smaller proportion will be detrimentally affected. The tree population within Newcastle's tree inventory represents a fairly rich community of trees given the area, with 187 species of tree identified. However, many of the inventory records provided are at the genus level only, indicating that species richness may actually be greater still.

Tree species from 4 continents are represented in Newcastle's tree inventory. The majority of the species are native to North America or Europe and Asia (see figure 2 below). However, further work would be required to assess the condition, size and populations of these trees and to provide recommendations on the best species to choose for any future plantings.

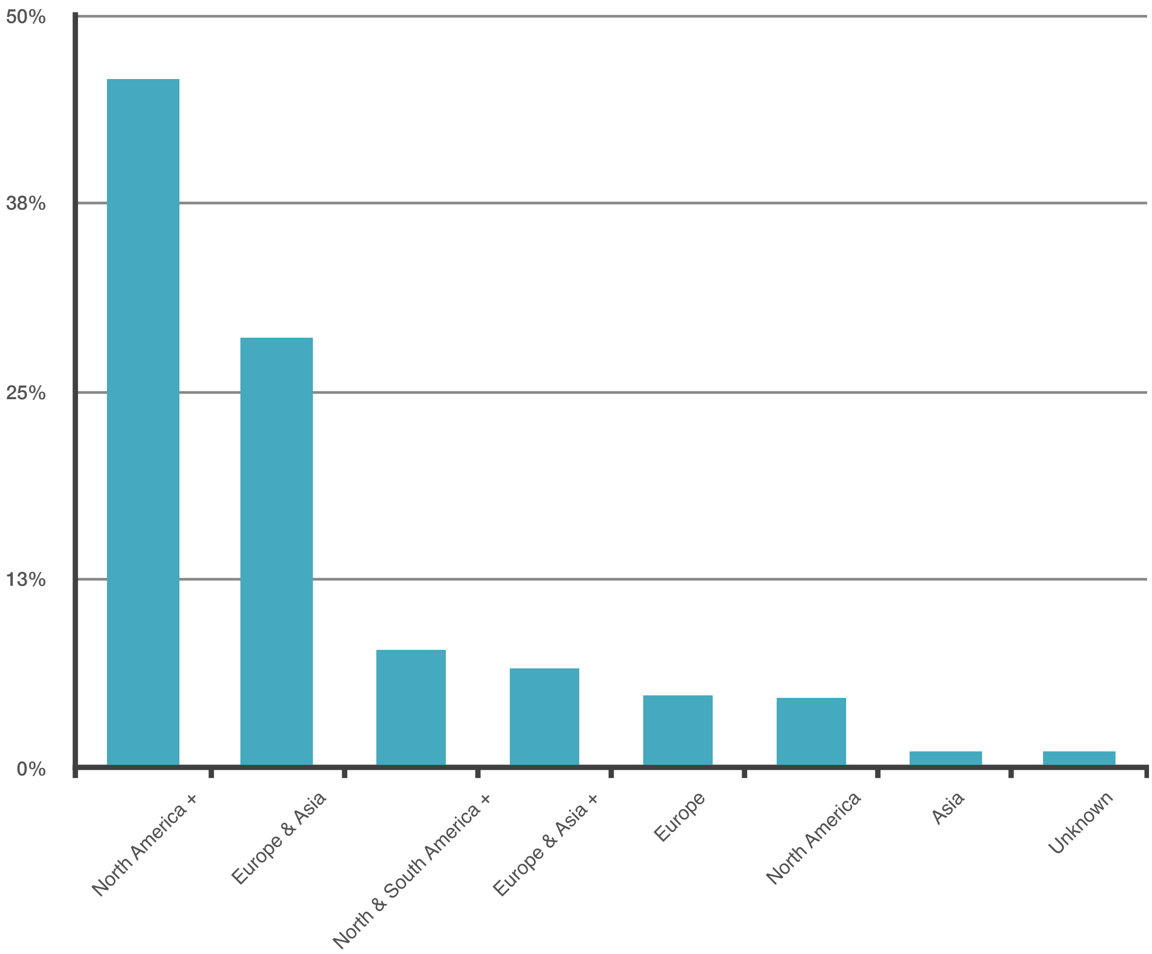

Figure 2: Origin of tree species

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 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 at breast height (dbh) at 1.3m. Figure 3 (below) shows the percentage of tree population for the ten most common trees by dbh class.

The size class distribution of trees within Newcastle's tree inventory appears to be based on a younger stock of trees. However, the dbh size classes in the supplied data means that it is difficult to compare the results with other studies. Improving structural diversity increases the overall resilience of the tree stock.

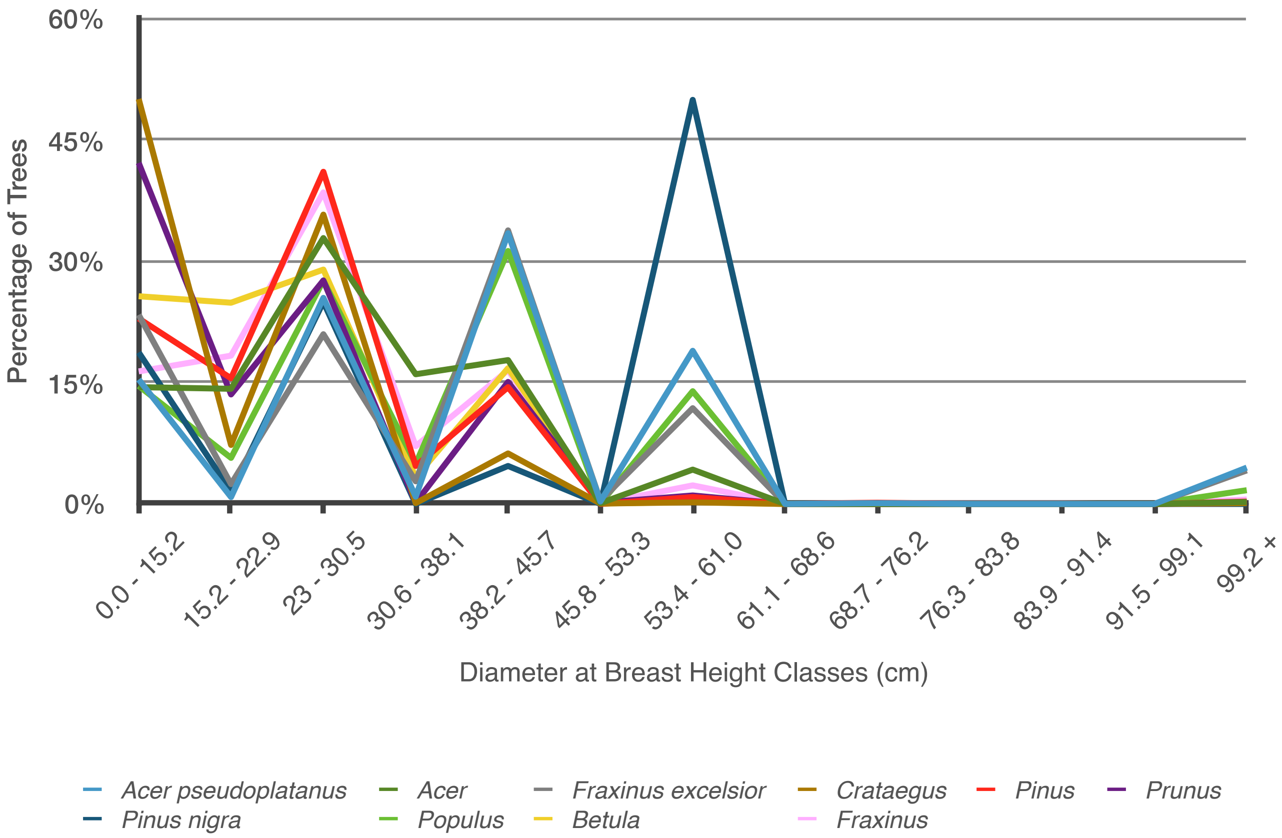

Figure 3: Composition (%) of tree population by DBH class

Leaf Area and Population

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

Within Newcastle's tree inventory, total leaf area is estimated at 32,003,400m^2. If all the layers of leaves within the tree canopies were spread out, they would cover an area approximately 8 times the size of The Town Moor (which covers an area of approximately 400,000m^2).

The three most dominant species in terms of leaf area are the sycamore (*Acer pseudoplatanus* - which has 19.8% of the total leaf area for all trees), Maples (*Acer,* at 18.4%) and European ash (*Fraxinus Excelsior* at 8.8%).

Figure 4 (below) shows the top ten dominant trees' contributions to total leaf area. In total these ten species, representing 65% of the tree population, contribute 74% of the total leaf area. The remaining 35% of tree population (not included in fig 4) provide the remaining 26% of leaf area.

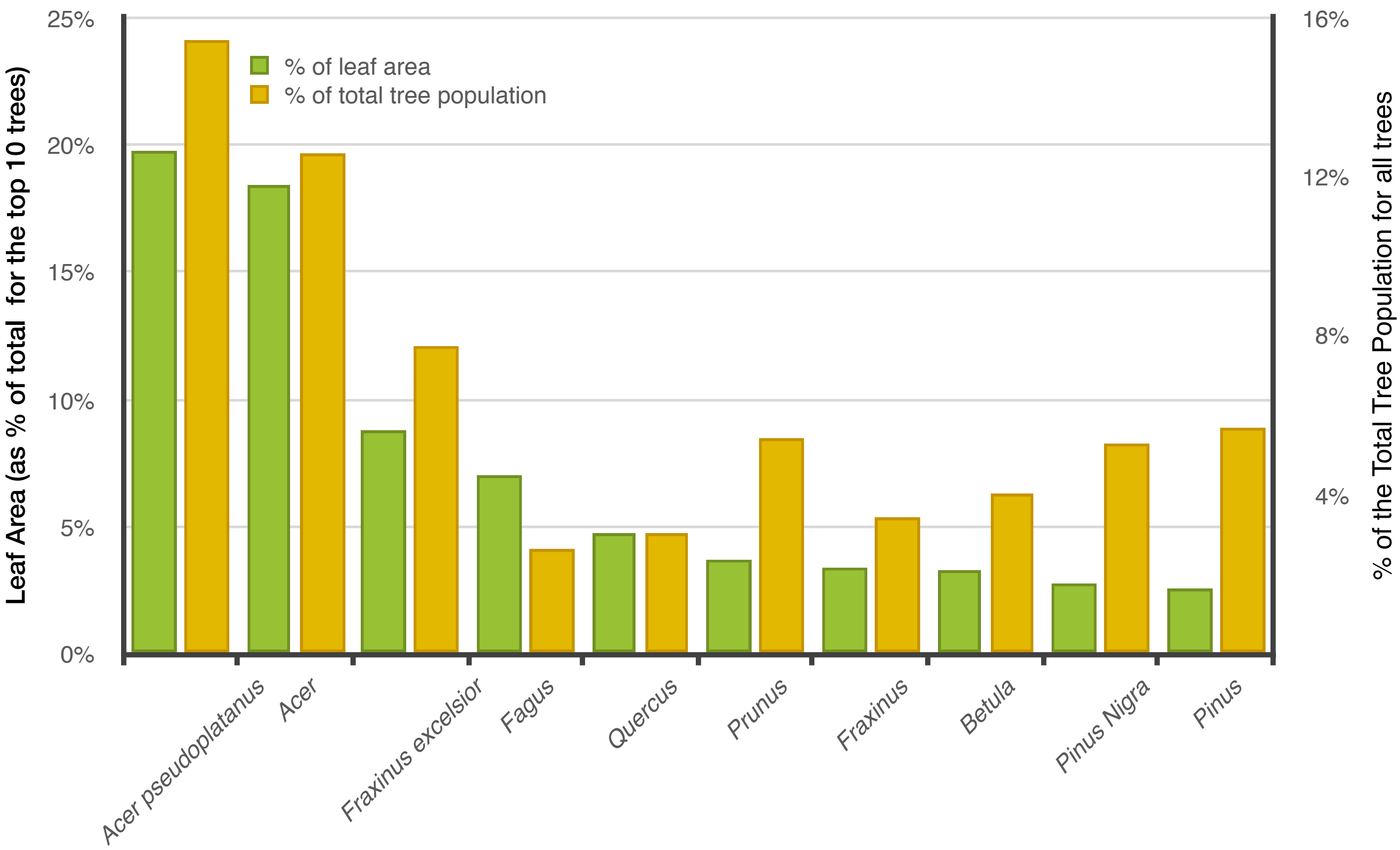

Figure 4: Percentage leaf area and population of the ten most dominant trees

Results - Ecosystem Services Resource

Air Pollution Removal

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

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

Trees 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 the urban heat island effect. Eco accounts for both reduction of ozone and production of VOCs within its algorithms and, as shown in figure 5, Eco estimated that Newcastle's Council-managed trees remove more ozone than they produce[8].

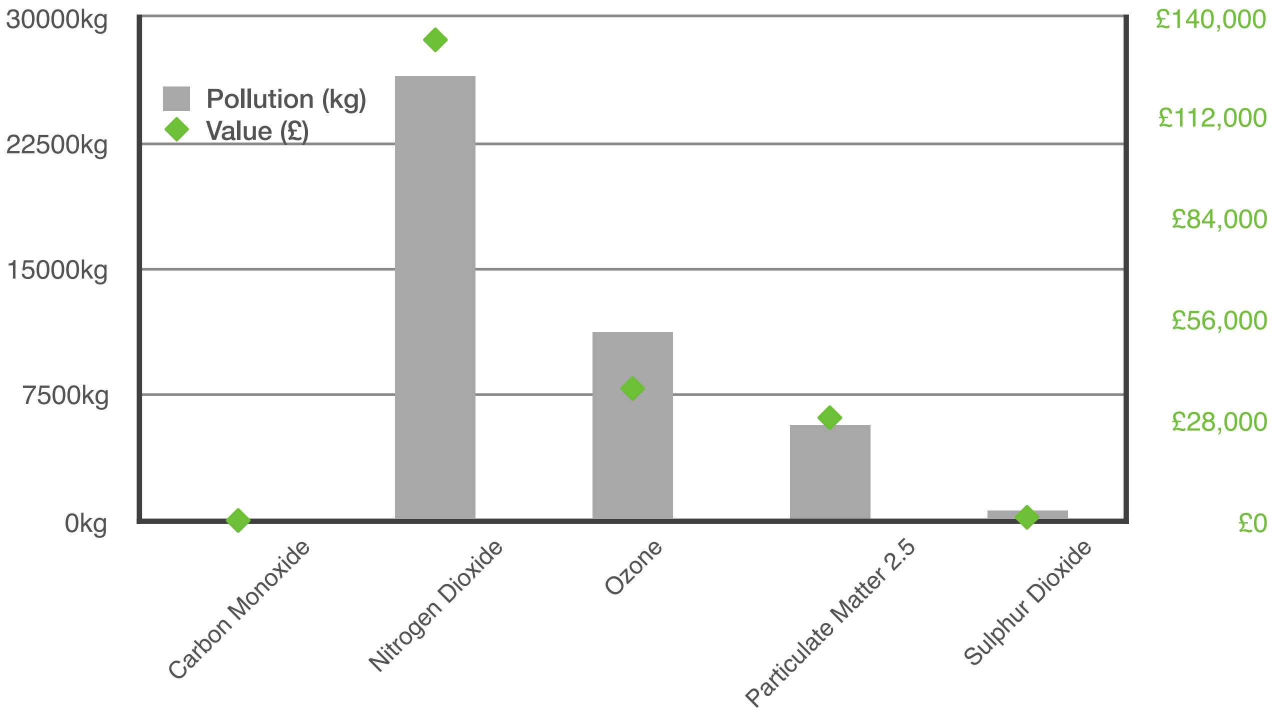

Figure 5: Value of the pollutants removed and quantity per-annum within Newcastle's Council tree inventory

Note: Valuation methods used are UK social damage cost (UKSDC) where they are available - where there are no UK figures, the US externality cost (USEC) is used as a substitution.

5 Tiwary et al., 2009

6 Nowak et al., 2000

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

8 Nowak et al., 2006, Escobedo and Nowak 2009

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

Figure 6 (below) shows the breakdown for the top ten pollution removing tree species in Newcastle's LA tree inventory. As different species can capture different sizes of particulate matter,[9] it is recommended that a broad range of species should be considered for planting in any air quality strategy.

It is interesting to note that despite being the 4th most common species/genus, *Crataegus* is not in the top 10 for air pollution removal - due to its smaller size and leaf area. This illustrates how large trees provide more benefits than smaller specimens.

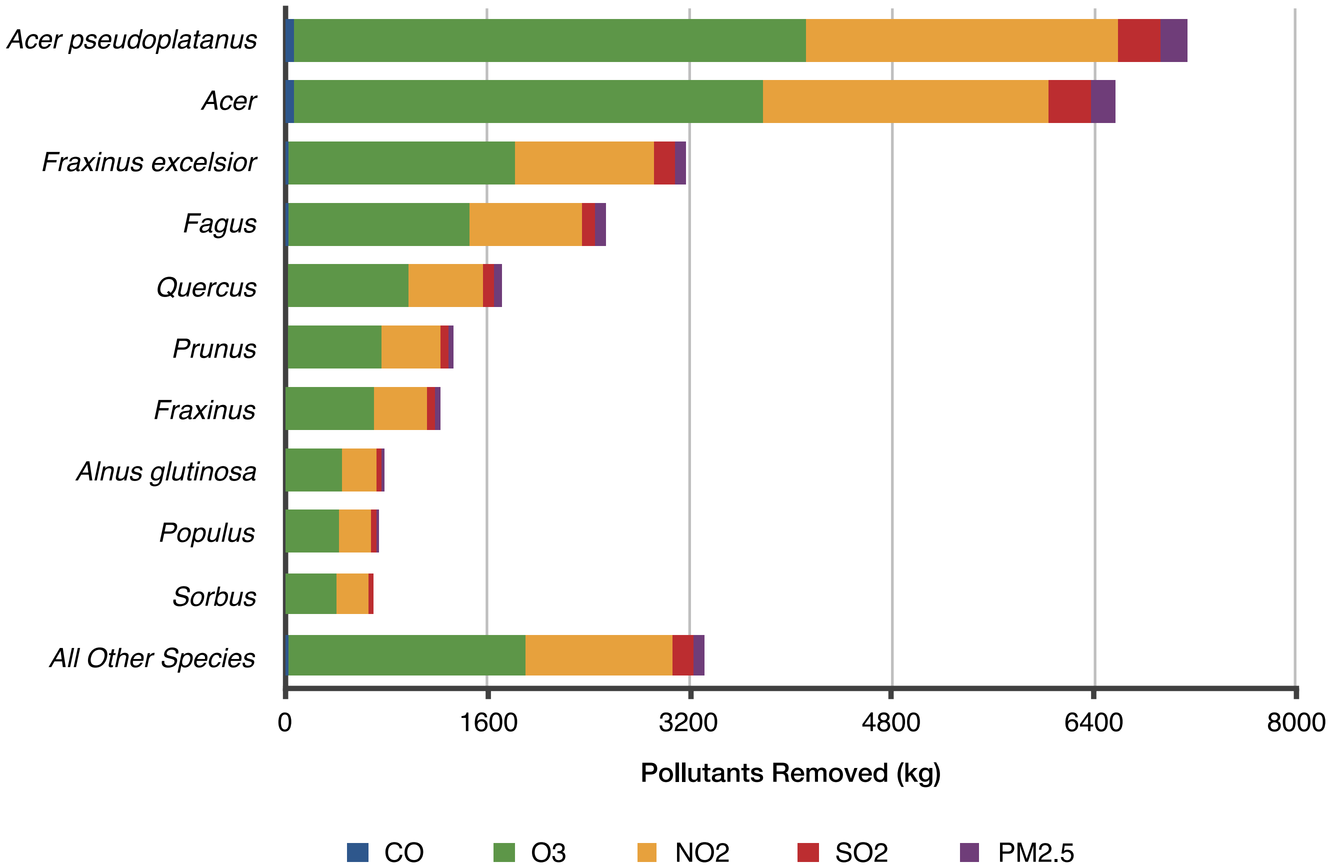

Figure 6: Pollution removal by tree species

[9] 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 state and 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
Liriodendron chinense	1
Cedrus deodara	2
Aesuclus hippocastanum	3
Acer platanoides	4
Corylus colurna	5
Picea rubens	6
Tilia tomentosa	7
Fraxinus excelsior	8
Carpinus betulus	9
Cupressus macrocarpa	10

Table 3: Top ten best pollution removing species in Newcastle

Comparing the list in table 2 with the results from Newcastle's Council tree inventory, there are two species within the top ten pollution removing trees (*Acer platanoides* and *Fraxinus excelsio*r - and highlighted in red). To maximise the potential pollution removal in the future, it would be worth considering planting more of the species listed in table 3. Of course, local requirements and site limitations would also need to be taken into account.

Carbon Storage

The main driving force behind climate change is the concentration of carbon dioxide (CO_2) in the atmosphere. Trees can help mitigate climate change by storing and sequestering atmospheric carbon as part of the carbon cycle. Since about 50% of wood by dry weight is comprised of carbon, tree stems and roots can store up to several tons of carbon for decades or even centuries[10] .

Overall the trees in Newcastle's Council tree inventory store an estimated 52,028 tonnes of carbon with a value of £12,782,752.

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

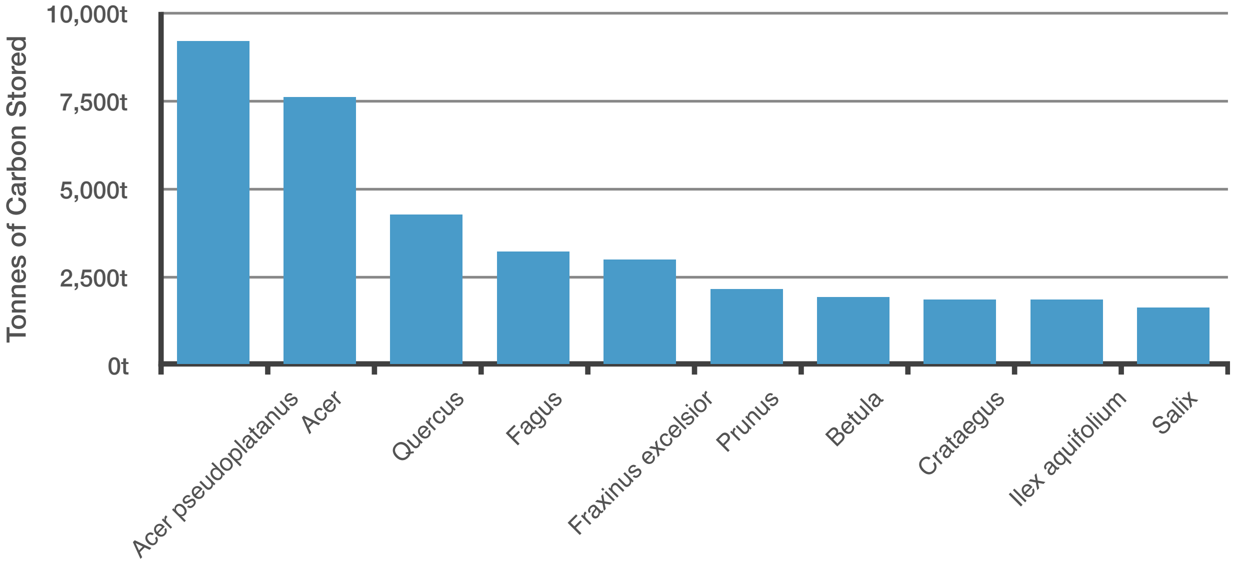

Figure 7: Carbon storage (tonnes) for top ten tree species

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

10 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 the CO_2 equivalent value before being multiplied by the unit cost for carbon. The current (2019) UK social cost is £67 / tonne.

Newcastle's Council managed trees sequester an estimated 1,550 tonnes of carbon per year, with a value of £380,837. Table 4 (below) shows the ten trees that sequester the most carbon per year and the value of the benefit derived from the sequestration of this atmospheric carbon.

Species	Carbon Sequestration (tonnes/yr)	CO_2 Equivalent (tonnes/yr)	Carbon Sequestration (£/yr)
Acer pseudoplatanus	256.83	941.81	£63,101
Acer	224.70	823.98	£55,207
Fraxinus excelsior	107.35	393.64	£26,374
Quercus	103.88	380.94	£25,523
Prunus	84.13	308.51	£20,670
Fagus	77.85	285.48	£19,127
Crataegus	73.24	268.58	£17,995
Betula	67.86	248.85	£16,673
Populus	50.14	183.87	£12,319
Fraxinus	47.19	173.04	£11,594
All Other Species	456.89	1675.42	£112,253
Total	1550.08	5684.13	£380,837

Table 4: Carbon sequestration by species

Of the entire tree species inventoried, the *Acer pseudoplatanus* store and sequester the most carbon, adding approximately 257 tonnes in the study year to the current *Acer pseudoplatanus* carbon storage of 9217 tonnes.

For comparison, the average newly registered car in the UK produces 34g carbon per km[11]. Carbon sequestration in Newcastle's tree inventory therefore accounts for around 45,590,588 vehicle km per year.

[11] 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[12].

In urban areas, the large extent of impervious surfaces increases the amount of runoff. However, trees are very effective at reducing surface runoff[13]. 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 Newcastle's Council tree inventory reduce runoff by an estimated 60,423 m^3 a year with an associated value of £91,605.

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

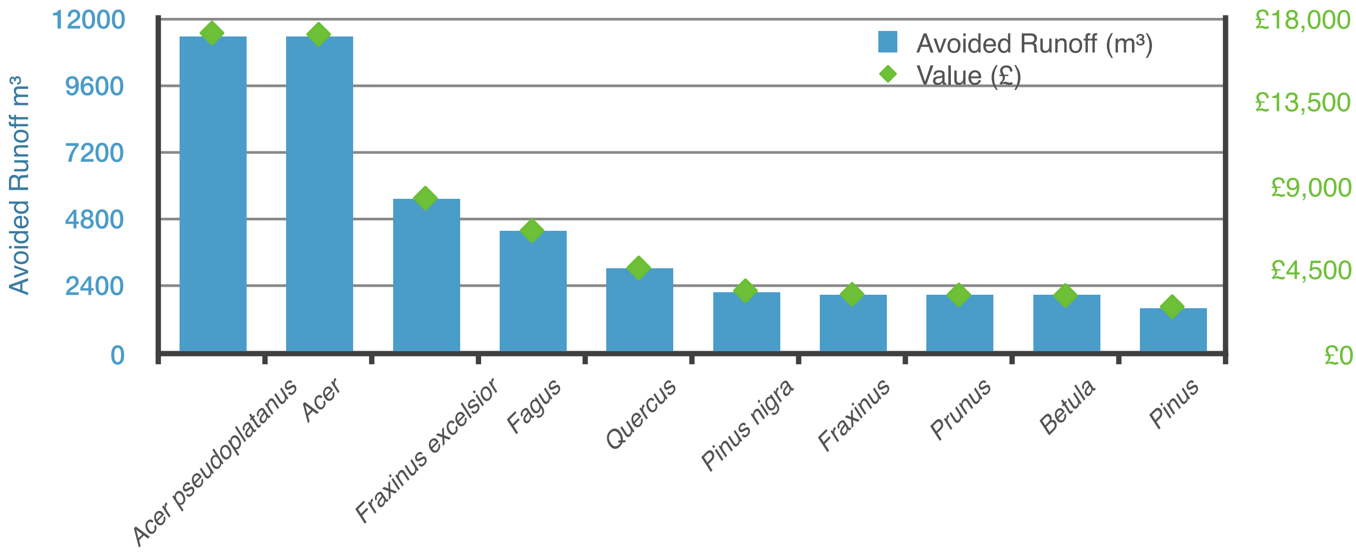

Figure 8: Avoided runoff by top ten species

The trees in Newcastle's Council tree inventory play an important role in reducing runoff: *Acer pseudoplatanus* intercepts the largest proportion of the precipitation for a species. This is due to the trees' population, canopy size and leaf morphology.

12 Hirabayashi 2012

13 Trees in Hard Landscapes (TDAG) 2014

Potential Pests and Diseases

Various insects 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) and Ash Dieback have been selected to illustrate how the results from this survey can be used to estimate the potential pest impacts on the trees in Newcastle's Council tree inventory.

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

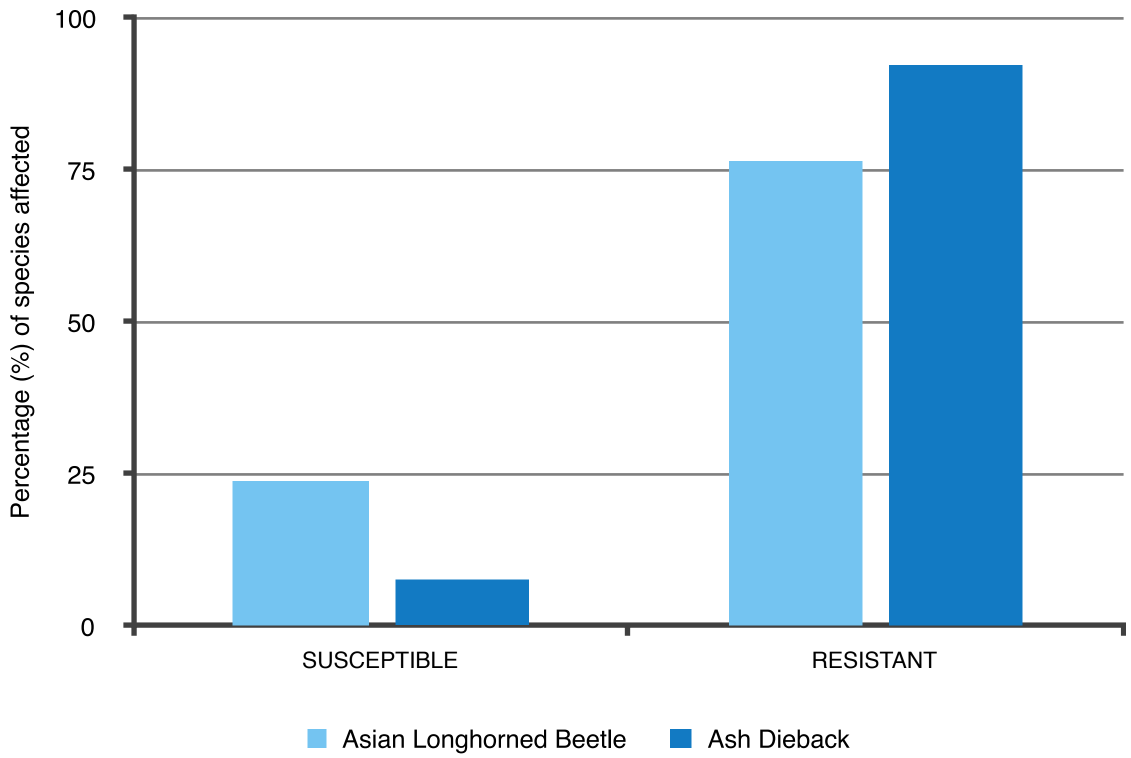

Figure 9: Potential pest impacts on Newcastle's LA tree population

ALB is an insect that bores into and has the potential to kill off parts of a wide range of hardwood species. This beetle could affect around 23.7% (or 45,626) of the trees in the Newcastle's Council tree inventory, including Sycamore (*Acer pseudoplatanus*) which makes up around 15.4% of the tree population.

This beetle has only recently been found in the south east of England and originates from Asia. If the beetle were to become established in Britain there is likely to be extensive damage to both urban and woodland/forest trees.

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 3rd most common species in Newcastle's Council tree inventory, accounting for 7.7% of the population (or 16,377 trees). Ash trees can be large in stature and provide a significant amount of ecosystem services to Newcastle and so their replacement should they perish would be costly (figure 10).

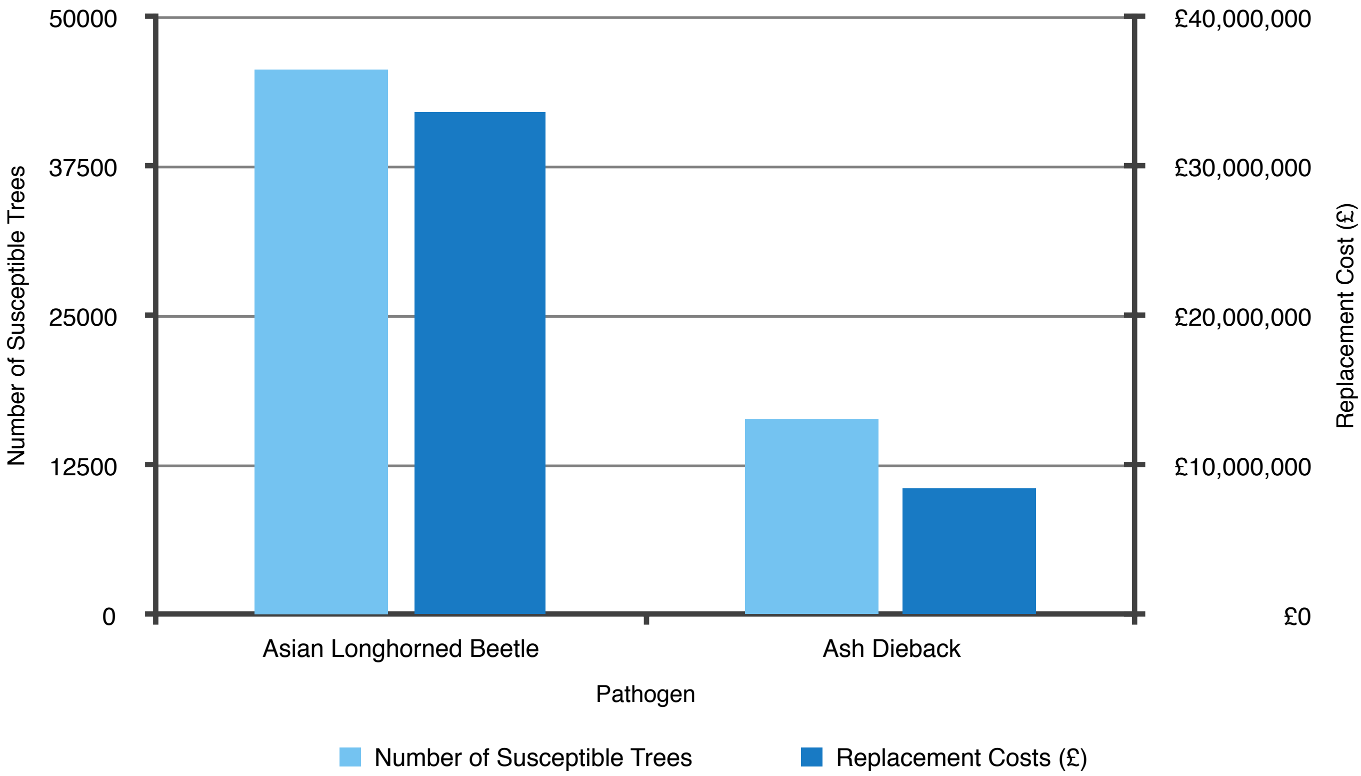

Figure 10: Potential replacement cost of pest impacts

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[14].

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

The total value of all trees in the study area as estimated by Eco currently stands at £141,879 million. *Acer pseudoplatanus* is the most valuable species of tree, on account of both its size and population, followed by *Acer* and *Quercus*. These three species (or genera) of tree account for £54,682 million (39%) of the total replacement cost of the trees in Newcastle's Local Authority tree inventory.

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

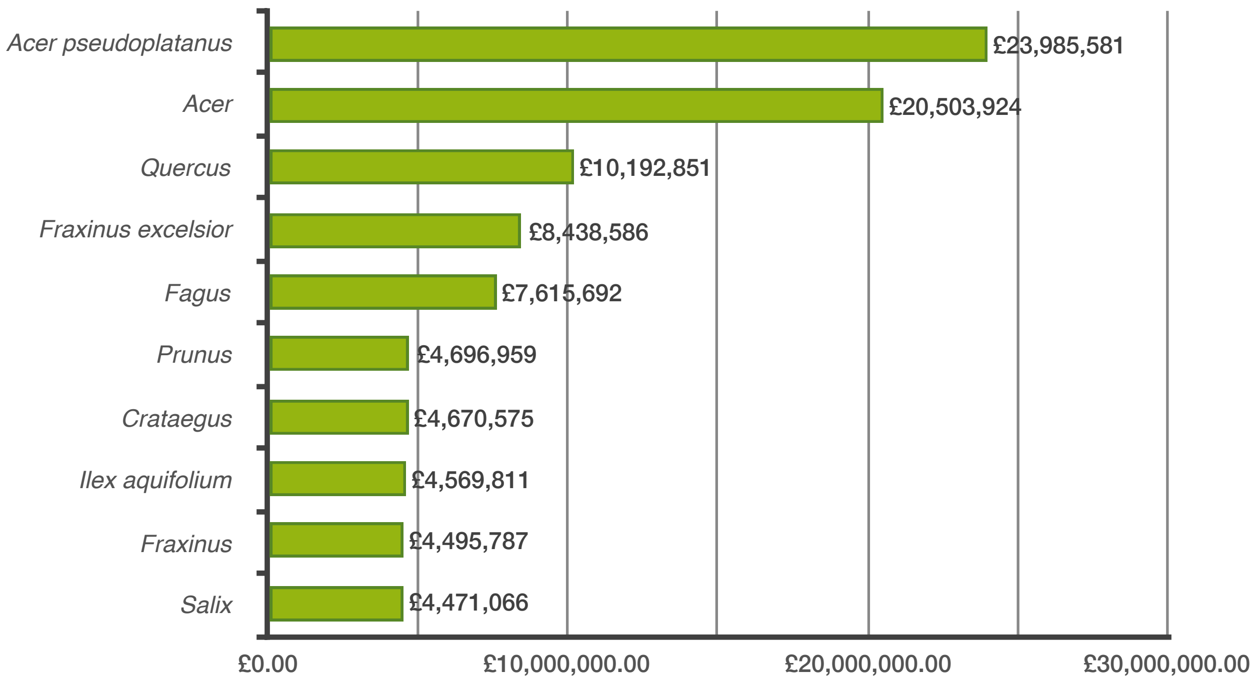

Figure 11: Replacement cost for top ten trees

[14] Hollis, 2007

Using this study

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

For example:

- Data can be used to inform species selection for increased tree diversity thereby lessening the impacts from potential threats like *Hymenoscyphus fraxineus* (formerly *Chalara fraxinea*), more commonly known as Ash Dieback).
- Data can be used to produce educational information about Newcastle's trees (e.g. informational tree tags).
- Using the data for cost benefit analyses 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 Newcastle City Council'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 together with an ancient tree management plan to include non-natives and heritage trees to broaden the potential for the Newcastle's Council tree inventory trees to build resilience to future change.

Conclusions

Newcastle City Council's tree inventory generally has a good species and age diversity. This will provide some resilience from possible future influences such as climate change and pest and disease outbreaks. The role of Newcastle's trees in complementing people's health is clear. Newcastle's Council-managed trees provide a valuable benefit - worth over £14,253,000 in ecosystem services each year.

However, it is recommended that records for all Council-managed trees (all trees not on private land) are obtained so that the City Council can better understand the full value of its tree stock.

In terms of structural diversity the *Acer pseudoplatanus* have the largest proportion of trees in the larger size classes but other tree species such as *Populus and Fraxinus excelsior* are also well represented. 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.

Newcastle's Council tree inventory is quite dependant on the top 3 species (by dominance - *Acer pseudoplatanus, Populus* and *Fraxinus excelsior*) for the delivery of ecosystem services (32% of population, 30.6% of leaf area and 26.4% of all carbon stored in the trees). Newcastle's Council tree inventory 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 and reduce reliance on a small number of species.

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

The extent of these benefits needs to be recognised, and strategies and policies that will serve to conserve this important resource (through education for example) would be one way to address this. 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 investigated through the production of an 'Urban Forest Masterplan'.

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 Newcastle 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, such as species choice for example.

The challenge now is to ensure that policy makers and practitioners take full account of Newcastle's Council-managed 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 Newcastle's Council tree inventory provide benefits that include carbon storage and sequestration and air pollutant removal. To estimate the relative value of these benefits, tree benefits were compared to estimates of average carbon emissions and average family car emissions. These figures should be treated as a guideline only as they are largely based on US values (see footnotes).

Carbon storage is equivalent to:

- Annual carbon (C) emissions from 45,376 family cars
- Annual C emissions from 18,516 single-family houses

Nitrogen dioxide removal is equivalent to:

- Annual nitrogen dioxide emissions from 2,151 family cars
- Annual nitrogen dioxide emissions from 1,053 single-family houses

Sulphur dioxide removal is equivalent to:

- Annual sulphur dioxide emissions from 22,334 family cars

Oxygen Production is equivalent to:

- Annual Oxygen intake from 6,762,116 people (21 times the population of Newcastle (2018))

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
Acer pseudoplatanus	19.85	15.40	35.24
Acer	18.36	12.57	30.93
Fraxinus excelsior	8.76	7.66	16.42
Fagus	7.00	2.57	9.57
Prunus	3.75	5.43	9.18
Crataegus	1.74	6.72	8.46
Pinus	2.57	5.73	8.30
Pinus nigra	2.83	5.34	8.18
Quercus	4.72	3.03	7.75
Betula	3.26	3.96	7.21
Fraxinus	3.40	3.43	6.83
Populus	2.03	3.98	6.01
Sorbus	2.03	2.71	4.74
Alnus glutinosa	2.14	2.33	4.48
Tilia	1.93	1.69	3.62
Corylus avellana	1.27	1.52	2.79
Salix	1.45	1.09	2.54
Populus nigra 'Italica'	0.74	1.21	1.96
Aesculus hippocastanum	1.19	0.51	1.69
Populus alba	0.51	1.10	1.61
Rosa	0.60	0.77	1.38
Ilex aquifolium	0.60	0.77	1.37
Aesculus	0.86	0.44	1.31
Acer platanoides	0.75	0.40	1.15
Malus	0.49	0.64	1.12
Tilia x europaea	0.79	0.32	1.12
Betula pendula	0.40	0.71	1.11
Ulmus	0.41	0.64	1.05
Fagus sylvatica	0.66	0.18	0.83
Sambucus nigra	0.15	0.67	0.83
Larix decidua	0.34	0.44	0.77

Species	Percent Population	Percent Leaf Area	Dominance Value
Prunus laurocerasus	0.19	0.52	0.71
Prunus avium	0.24	0.42	0.66
Crataegus monogyna	0.12	0.45	0.57
Pinus sylvestris	0.06	0.48	0.54
Cupressocyparis leylandii	0.18	0.34	0.52
Alnus	0.20	0.29	0.49
Carpinus betulus	0.19	0.27	0.46
Cedrus	0.04	0.41	0.46
Taxus baccata	0.19	0.20	0.39
Acer campestre	0.22	0.17	0.39
Taxus	0.15	0.14	0.29
Sorbus aria	0.15	0.12	0.27
Juglans	0.07	0.17	0.24
Quercus robur	0.15	0.08	0.23
Ilex	0.07	0.15	0.23
Tilia cordata	0.07	0.12	0.20
Sorbus intermedia	0.11	0.08	0.20
Platanus	0.12	0.07	0.19
Ulex europaeus	0.04	0.15	0.19
Rhododendron	0.05	0.12	0.16
Salix babylonica	0.10	0.06	0.16
Salix alba	0.08	0.08	0.16
Acer palmatum	0.05	0.05	0.10
Salix caprea	0.05	<0.01	0.10
Laburnum	0.04	0.05	0.09
Sorbus aucuparia	0.03	0.06	0.08
Tilia x vulgaris	0.05	<0.01	0.08
Tilia americana	0.04	<0.01	0.08
Populus tremula	0.03	<0.01	0.08
Chamaecyparis	0.02	0.06	0.08
Cupressus	0.02	0.05	0.07
Sequoiadendron giganteum	0.05	<0.01	0.06
Populus nigra	0.03	<0.01	0.06
Betula utilis	0.01	<0.01	0.06

Species	Percent Population	Percent Leaf Area	Dominance Value
Ligustrum	0.01	<0.01	0.06
Ulmus glabra	0.03	<0.01	0.05
Pyrus	0.01	<0.01	0.05
Salix fragilis	0.03	<0.01	0.05
Abies	0.02	<0.01	0.05
Platanus x acerifolia	0.04	<0.01	0.05
Cotoneaster	0.01	<0.01	0.05
Prunus domestica	0.01	<0.01	0.04
Pinus nigra ssp. salzmannii	0.03	<0.01	0.04
Prunus padus	0.02	<0.01	0.04
Acer saccharinum	0.02	<0.01	0.03
Ulmus procera	0.02	<0.01	0.03
Carpinus betulus 'Fastigiata'	0.01	<0.01	0.03
Juglans regia	0.02	<0.01	0.03
Juniperus	0.02	<0.01	0.03
Robinia	0.01	<0.01	0.02
Prunus Kanzan	0.01	<0.01	0.02
Larix	0.01	<0.01	0.02
Castanea sativa	0.01	<0.01	0.02
Chamaecyparis lawsoniana	0.01	<0.01	0.02
Prunus lusitanica	<0.01	<0.01	0.02
Prunus cerasifera	0.01	<0.01	0.02
Laurus	0.01	<0.01	0.02
Cupressocyparis	0.01	<0.01	0.02
Prunus sargentii	0.01	<0.01	0.01
Picea abies	0.01	<0.01	0.01
Malus sylvestris	<0.01	<0.01	0.01
Prunus spinosa	0.01	<0.01	0.01
Fagus sylvatica 'Purpurea'	0.01	<0.01	0.01
Liriodendron tulipifera	0.01	<0.01	0.01
Alnus cordata	0.01	<0.01	0.01
Populus x canadensis	0.01	<0.01	0.01
Betula pubescens	<0.01	<0.01	0.01
Alnus incana	<0.01	<0.01	0.01

Species	Percent Population	Percent Leaf Area	Dominance Value
Sorbus domestica	<0.01	<0.01	0.01
Picea	<0.01	<0.01	0.01
Juniperus communis	<0.01	<0.01	0.01
Cercidiphyllum japonicum	<0.01	<0.01	0.01
Taxus baccata 'fastigiata'	<0.01	<0.01	0.01
Betula ermanii	<0.01	<0.01	0.01
Rhus	<0.01	<0.01	0.01
Laurus nobilis	<0.01	<0.01	0.01
Liquidambar styraciflua	<0.01	<0.01	0.01
Robinia pseudoacacia	<0.01	<0.01	0.01
Fraxinus excelsior 'Pendula'	<0.01	<0.01	0.01
Corylus colurna	<0.01	<0.01	0.01
Populus x canescens	<0.01	<0.01	0.01
Pyrus calleryana 'Chanticleer'	<0.01	<0.01	0.01
Amelanchier	<0.01	<0.01	<0.01
Cedrus deodara	<0.01	<0.01	<0.01
Ungnadia	<0.01	<0.01	<0.01
Acacia	<0.01	<0.01	<0.01
Eucalyptus	<0.01	<0.01	<0.01
Quercus cerris	<0.01	<0.01	<0.01
Acer saccharum	<0.01	<0.01	<0.01
Tilia tomentosa	<0.01	<0.01	<0.01
Crataegus prunifolia	<0.01	<0.01	<0.01
Quercus rubra	<0.01	<0.01	<0.01
Pyrus communis	<0.01	<0.01	<0.01
Syringa	<0.01	<0.01	<0.01
Ailanthus altissima	<0.01	<0.01	<0.01
Quercus/live ilex	<0.01	<0.01	<0.01
Betula albo-sinensis	<0.01	<0.01	<0.01
Laburnum anagyroides	<0.01	<0.01	<0.01
Magnolia	<0.01	<0.01	<0.01
Pinus contorta	<0.01	<0.01	<0.01
Pterocarya fraxinifolia	<0.01	<0.01	<0.01
Cedrus atlantica	<0.01	<0.01	<0.01

Species	Percent Population	Percent Leaf Area	Dominance Value
Acer rubrum	<0.01	<0.01	<0.01
Prunus subhirtella	<0.01	<0.01	<0.01
Quercus petraea	<0.01	<0.01	<0.01
Quercus robur 'Fastigiata'	<0.01	<0.01	<0.01
Acer griseum	<0.01	<0.01	<0.01
Amelanchier arborea	<0.01	<0.01	<0.01
Thuja	<0.01	<0.01	<0.01
Cedrus libani	<0.01	<0.01	<0.01
Acer davidii	<0.01	<0.01	<0.01
Hippophae rhamnoides	<0.01	<0.01	<0.01
Fraxinus ornus	<0.01	<0.01	<0.01
Ginkgo biloba	<0.01	<0.01	<0.01
Sequoia sempervirens	<0.01	<0.01	<0.01
Acer platanoides 'Crimson King'	<0.01	<0.01	<0.01
Salix matsudana 'Tortuosa'	<0.01	<0.01	<0.01
Ulmus 'Sapporo Autunm Gold'	<0.01	<0.01	<0.01
Malus domestica	<0.01	<0.01	<0.01
Tilia platyphyllos	<0.01	<0.01	<0.01
Gleditsia triacanthos	<0.01	<0.01	<0.01
Sorbus torminalis	<0.01	<0.01	<0.01
Quercus palustris	<0.01	<0.01	<0.01
Crataegus laevigata	<0.01	<0.01	<0.01
Crataegus x lavallei	<0.01	<0.01	<0.01
Mespilus germanica	<0.01	<0.01	<0.01
Metasequoia glyptostroboides	<0.01	<0.01	<0.01
Quercus coccinea	<0.01	<0.01	<0.01
Juniperus chinensis	<0.01	<0.01	<0.01
Acer capillipes	<0.01	<0.01	<0.01
Betula papyrifera	<0.01	<0.01	<0.01
Nothofagus	<0.01	<0.01	<0.01
Nothofagus antarctica	<0.01	<0.01	<0.01
Salix x sepulcralis Simonkai	<0.01	<0.01	<0.01
Tilia cordata 'Greenspire'	<0.01	<0.01	<0.01

Species	Percent Population	Percent Leaf Area	Dominance Value
Araucaria araucana	<0.01	<0.01	<0.01
Populus balsamifera	<0.01	<0.01	<0.01
Picea pungens	<0.01	<0.01	<0.01
Pinus wallichiana	<0.01	<0.01	<0.01
Crataegus crus-galli	<0.01	<0.01	<0.01
Arbutus	<0.01	<0.01	<0.01
Cornus kousa	<0.01	<0.01	<0.01
Zelkova serrata	<0.01	<0.01	<0.01
Abies koreana	<0.01	<0.01	<0.01
Catalpa bignonioides	<0.01	<0.01	<0.01
Malus tschonoskii	<0.01	<0.01	<0.01
Picea omorika	<0.01	<0.01	<0.01
Prunus dulcis	<0.01	<0.01	<0.01
Prunus serrula	<0.01	<0.01	<0.01
Rhamnus cathartica	<0.01	<0.01	<0.01
Ulmus minor	<0.01	<0.01	<0.01
Parrotia persica	<0.01	<0.01	<0.01
Pyrus salicifolia	<0.01	<0.01	<0.01
Thuja plicata	<0.01	<0.01	<0.01

Appendix III. Tree Values by Species

Species	Trees	Carbon Storage (Tonnes)	Gross Carbon Seq (Tonnes/Yr)	Avoided Runoff (m^3/Yr)	Pollution Removal (Tonne/Yr)	Replacement Cost (£)
Acer pseudoplatanus	32920	33799.43	941.81	11338.29	7.14	£23,985,581
Acer	26878	28044.57	823.98	11293.14	6.56	£20,503,924
Quercus	6476	15579.22	380.94	3026.93	1.70	£10,192,851
Fraxinus excelsior	16372	10820.76	393.64	5495.16	3.17	£8,438,586
Fagus	5504	11714.46	285.48	4345.83	2.53	£7,615,692
Prunus	11608	7997.77	308.51	2072.44	1.34	£4,696,959
Crataegus	14371	6761.08	268.58	1108.30	0.63	£4,670,575
Ilex aquifolium	1637	6732.06	110.40	347.45	0.22	£4,569,811
Fraxinus	7326	5422.50	173.04	2091.94	1.22	£4,495,787
Salix	2330	5965.75	122.37	866.95	0.52	£4,471,066
Sorbus	5790	5773.81	164.05	1131.47	0.71	£4,460,789
Populus	8501	5775.02	183.87	1088.35	0.73	£4,445,285
Pinus nigra	11422	2971.45	111.83	2219.37	1.03	£4,389,592
Pinus	12245	3769.85	134.86	1657.62	0.93	£4,309,415
Betula	8456	6913.31	248.85	2051.40	1.18	£4,217,137
Tilia	3608	2448.69	73.99	1065.33	0.67	£3,127,265
Corylus avellana	3248	3106.21	89.10	804.07	0.46	£2,065,589
Tilia x europaea	691	1449.25	31.82	446.54	0.28	£2,052,610
Alnus glutinosa	4983	2658.43	129.26	1460.61	0.78	£1,801,148
Fagus sylvatica	379	2792.29	36.33	365.83	0.23	£1,610,794
Aesculus hippocastanum	1088	2372.11	55.20	751.73	0.43	£1,235,254
Populus nigra 'Italica'	2597	1280.53	57.82	389.09	0.27	£1,197,892
Rosa	1654	1631.70	46.41	408.64	0.22	£1,195,467
Malus	1358	1164.20	42.80	300.25	0.17	£1,174,932
Acer platanoides	856	1300.13	32.71	426.32	0.26	£1,030,944
Aesculus	947	1505.82	39.58	524.43	0.31	£989,667
Populus alba	2349	689.04	44.37	239.18	0.19	£603,254
Betula pendula	1516	971.02	41.63	285.83	0.14	£597,496
Prunus avium	889	627.58	20.87	149.98	0.08	£451,095
Cupressocyparis leylandii	729	376.26	10.46	119.85	0.07	£426,726
Sambucus nigra	1440	603.52	26.66	134.38	0.06	£399,287

Species	Trees	Carbon Storage (Tonnes)	Gross Carbon Seq (Tonnes/Yr)	Avoided Runoff (m3/Yr)	Pollution Removal (Tonne/ Yr)	Replacement Cost (£)
Quercus robur	178	608.82	12.09	81.26	0.05	£371,758
Sorbus aria	253	376.09	11.83	90.97	0.05	£349,005
Ilex	329	405.35	10.50	41.31	0.03	£322,046
Sorbus intermedia	180	358.20	9.59	62.27	0.04	£316,080
Taxus baccata	438	232.01	6.24	106.22	0.07	£313,531
Alnus	615	392.86	13.50	114.12	0.07	£298,803
Carpinus betulus	571	345.54	11.34	108.28	0.07	£288,548
Taxus	300	204.73	4.99	84.14	0.05	£275,585
Salix babylonica	132	243.65	7.82	64.71	0.04	£240,033
Crataegus monogyna	960	346.93	16.22	74.61	0.04	£237,033
Rhododendron	248	334.32	9.59	24.83	0.02	£236,053
Larix decidua	932	223.28	11.96	195.50	0.12	£217,572
Salix alba	161	275.79	6.81	49.43	0.03	£209,068
Prunus laurocerasus	1108	300.51	15.57	144.10	0.07	£201,705
Acer campestre	359	266.84	9.82	122.21	0.08	£178,540
Ulmus	1368	391.55	17.54	247.65	0.14	£172,123
Platanus	146	167.90	5.01	66.95	0.04	£138,546
Salix caprea	96	168.62	4.36	34.56	0.02	£135,333
Tilia cordata	267	89.09	3.36	41.46	0.03	£118,714
Pinus nigra ssp. salzmannii	29	79.30	1.18	14.00	0.01	£111,616
Populus nigra	60	103.80	2.29	17.85	0.01	£93,315
Sequoiadendron giganteum	41	84.80	1.34	24.97	0.02	£91,984
Tilia x vulgaris	68	66.30	1.84	27.11	0.02	£89,636
Pinus sylvestris	1025	44.84	3.58	36.14	0.02	£78,913
Cupressus	110	65.03	1.80	10.47	0.01	£74,941
Cedrus	887	41.49	3.10	25.44	0.02	£72,930
Platanus x acerifolia	26	101.60	1.69	20.13	0.01	£72,922
Salix fragilis	56	92.71	2.31	17.04	0.01	£71,947
Populus tremula	101	60.21	2.45	18.70	0.01	£61,631
Acer palmatum	115	80.99	2.94	33.74	0.02	£61,033
Tilia americana	75	50.80	1.51	24.50	0.02	£60,796
Castanea sativa	11	87.80	1.09	8.19	0.01	£52,415

Species	Trees	Carbon Storage (Tonnes)	Gross Carbon Seq (Tonnes/Yr)	Avoided Runoff (m³/Yr)	Pollution Removal (Tonne/ Yr)	Replacement Cost (£)
Prunus padus	36	71.65	1.72	11.10	0.01	£47,958
Laburnum	110	81.80	2.65	22.19	0.01	£44,773
Juglans	365	45.35	2.98	45.06	0.02	£43,800
Sorbus aucuparia	118	49.62	2.12	15.45	0.01	£39,163
Laurus	17	45.60	0.88	4.67	0.00	£33,621
Chamaecyparis	125	26.98	1.06	9.56	0.01	£31,777
Prunus Kanzan	22	51.20	1.21	7.24	0.00	£29,505
Fagus sylvatica 'Purpurea'	5	38.20	0.59	5.29	0.00	£27,150
Acer saccharinum	36	31.58	0.83	9.98	0.01	£25,479
Robinia	26	29.50	0.89	6.85	0.00	£24,366
Ulex europaeus	327	23.20	2.20	32.99	0.01	£23,387
Pyrus	94	25.70	1.22	5.76	0.00	£22,551
Chamaecyparis lawsoniana	24	17.32	0.45	4.77	0.00	£21,502
Abies	56	21.47	0.92	15.72	0.01	£20,518
Juglans regia	16	18.49	0.66	10.82	0.01	£18,429
Juniperus	20	19.26	0.41	9.54	0.01	£18,418
Ulmus glabra	47	42.30	1.31	18.73	0.01	£18,331
Populus x canadensis	7	16.60	0.39	2.89	0.00	£17,367
Carpinus betulus 'Fastigiata'	34	21.40	0.83	8.10	0.01	£16,674
Cupressocyparis	22	13.45	0.30	3.10	0.00	£15,273
Fraxinus excelsior 'Pendula'	5	16.20	0.26	1.90	0.00	£14,891
Cedrus deodara	5	9.60	0.14	1.39	0.00	£14,446
Betula utilis	92	16.40	1.06	7.87	0.00	£14,127
Pyrus communis	5	16.00	0.26	0.70	<0.001	£12,482
Tilia tomentosa	2	9.60	0.13	1.59	0.00	£11,834
Prunus sargentii	13	18.80	0.56	3.76	0.00	£11,778
Cedrus libani	1	6.90	0.09	0.82	0.00	£11,766
Ulmus procera	29	25.41	0.81	12.46	0.01	£11,033
Prunus domestica	72	17.33	0.88	8.63	0.00	£9,012
Cotoneaster	77	14.61	0.83	8.58	0.00	£8,900
Prunus cerasifera	21	16.40	0.61	4.10	0.00	£8,734
Alnus cordata	11	9.50	0.36	2.97	0.00	£8,562

Species	Trees	Carbon Storage (Tonnes)	Gross Carbon Seq (Tonnes/Yr)	Avoided Runoff (m^3/Yr)	Pollution Removal (Tonne/ Yr)	Replacement Cost (£)
Malus sylvestris	17	10.56	0.39	2.96	0.00	£7,832
Quercus cerris	4	11.80	0.25	1.43	0.00	£7,817
Picea abies	9	10.42	0.26	5.29	0.00	£7,204
Populus x canescens	5	6.82	0.19	2.00	0.00	£6,909
Pinus contorta	2	4.30	0.07	0.98	0.00	£6,873
Picea	8	7.10	0.19	2.52	0.00	£6,856
Alnus incana	9	8.70	0.29	2.31	0.00	£6,597
Robinia pseudoacacia	6	8.90	0.22	1.70	0.00	£6,356
Betula ermanii	6	7.40	0.28	2.08	0.00	£5,970
Liriodendron tulipifera	13	5.60	0.18	3.11	0.00	£5,824
Acer saccharum	3	9.50	0.18	1.59	0.00	£5,816
Prunus spinosa	15	9.50	0.41	3.00	0.00	£5,699
Sorbus domestica	11	6.90	0.25	1.80	0.00	£5,246
Cedrus atlantica	3	2.50	0.06	0.66	<0.001	£4,858
Ailanthus altissima	3	8.00	0.15	1.18	0.00	£4,759
Ligustrum	101	6.30	0.67	10.05	0.00	£4,500
Laurus nobilis	7	5.70	0.22	1.61	0.00	£4,283
Quercus petraea	2	6.20	0.13	0.74	<0.001	£3,817
Eucalyptus	5	6.00	0.18	1.28	0.00	£3,398
Juniperus communis	9	3.40	0.11	2.25	0.00	£3,365
Betula pubescens	12	4.40	0.22	1.59	0.00	£3,125
Quercus rubra	4	3.90	0.12	1.01	0.00	£3,090
Larix	36	4.90	0.21	4.74	0.00	£2,966
Prunus lusitanica	30	3.41	0.30	2.93	0.00	£2,538
Pterocarya fraxinifolia	2	3.60	0.09	0.99	0.00	£2,304
Ungnadia	6	2.60	0.10	1.11	0.00	£1,823
Betula albo-sinensis	4	2.50	0.12	0.87	0.00	£1,625
Taxus baccata 'fastigiata'	12	0.85	0.06	0.69	<0.001	£1,585
Acacia	6	2.20	0.12	1.06	0.00	£1,565
Thuja	3	0.60	0.02	0.33	<0.001	£1,500
Sequoia sempervirens	1	1.00	0.03	0.59	<0.001	£1,424
Acer platanoides 'Crimson King'	1	1.90	0.05	0.58	<0.001	£1,382

Species	Trees	Carbon Storage (Tonnes)	Gross Carbon Seq (Tonnes/Yr)	Avoided Runoff (m^3/Yr)	Pollution Removal (Tonne/Yr)	Replacement Cost (£)
Populus balsamifera	1	1.20	0.03	0.19	<0.001	£1,382
Quercus/live ilex	5	2.10	0.10	0.65	<0.001	£1,275
Salix x sepulcralis Simonkai	1	1.70	0.04	0.26	<0.001	£1,190
Arbutus	1	1.70	0.04	0.09	<0.001	£1,190
Cercidiphyllum japonicum	12	1.26	0.10	0.78	<0.001	£1,108
Hippophae rhamnoides	3	1.60	0.07	0.24	<0.001	£1,063
Laburnum anagyroides	4	1.70	0.08	0.67	<0.001	£962
Syringa	7	1.10	0.07	0.18	<0.001	£939
Prunus subhirtella	3	1.40	0.07	0.50	<0.001	£892
Pyrus calleryana 'Chanticleer'	10	0.90	0.09	0.38	<0.001	£853
Rhus	13	0.80	0.09	0.29	<0.001	£832
Salix matsudana 'Tortuosa'	2	1.10	0.05	0.31	<0.001	£760
Malus domestica	2	1.10	0.05	0.30	<0.001	£760
Amelanchier	9	0.50	0.07	0.40	<0.001	£758
Liquidambar styraciflua	11	1.10	0.07	0.57	<0.001	£751
Crataegus prunifolia	7	0.90	0.06	0.28	<0.001	£711
Corylus colurna	9	0.55	0.07	0.80	<0.001	£664
Magnolia	4	0.70	0.05	0.51	<0.001	£663
Ulmus 'Sapporo Autunm Gold'	1	1.40	0.04	0.55	<0.001	£565
Acer griseum	3	0.80	0.04	0.45	<0.001	£515
Gleditsia triacanthos	2	0.60	0.04	0.20	<0.001	£512
Betula papyrifera	1	0.70	0.04	0.25	<0.001	£485
Crataegus crus-galli	1	0.50	0.03	0.11	<0.001	£453
Tilia cordata 'Greenspire'	1	0.40	0.02	0.23	<0.001	£433
Tilia platyphyllos	2	0.40	0.02	0.23	<0.001	£413
Juniperus chinensis	1	0.40	0.01	0.30	<0.001	£391
Araucaria araucana	1	0.30	0.01	0.18	<0.001	£380
Pinus wallichiana	1	0.30	0.01	0.12	<0.001	£380
Quercus robur 'Fastigiata'	4	0.20	0.04	0.22	<0.001	£345
Acer capillipes	1	0.60	0.02	0.25	<0.001	£327
Acer rubrum	4	0.30	0.04	0.36	<0.001	£326

Species	Trees	Carbon Storage (Tonnes)	Gross Carbon Seq (Tonnes/Yr)	Avoided Runoff (m^3/Yr)	Pollution Removal (Tonne/ Yr)	Replacement Cost (£)
Amelanchier arborea	4	0.20	0.03	0.17	<0.001	£326
Nothofagus	1	0.60	0.02	0.26	<0.001	£306
Nothofagus antarctica	1	0.60	0.02	0.26	<0.001	£306
Picea pungens	1	0.50	0.01	0.14	<0.001	£285
Acer davidii	3	0.20	0.03	0.27	<0.001	£240
Fraxinus ornus	3	0.20	0.02	0.14	<0.001	£184
Sorbus torminalis	2	0.10	0.02	0.12	<0.001	£173
Quercus coccinea	2	0.10	0.01	0.09	<0.001	£173
Ginkgo biloba	3	0.20	0.02	0.12	<0.001	£170
Crataegus laevigata	2	0.10	0.02	0.09	<0.001	£152
Quercus palustris	2	0.10	0.01	0.10	<0.001	£135
Metasequoia glyptostroboides	2	0.10	0.01	0.08	<0.001	£120
Rhamnus cathartica	1	0.30	0.01	0.05	<0.001	£119
Crataegus x lavallei	2	0.10	0.01	0.08	<0.001	£119
Mespilus germanica	2	0.10	0.01	0.09	<0.001	£89
Zelkova serrata	1	0.10	0.01	0.06	<0.001	£76
Malus tschonoskii	1	0.10	0.01	0.06	<0.001	£68
Pyrus salicifolia	1	0.10	0.01	0.03	<0.001	£68
Catalpa bignonioides	1	0.10	0.01	0.05	<0.001	£60
Parrotia persica	1	0.10	0.01	0.04	<0.001	£60
Prunus serrula	1	0.10	0.01	0.05	<0.001	£57
Cornus kousa	1	0.10	0.01	0.08	<0.001	£57
Picea omorika	1	0.10	0.01	0.06	<0.001	£57
Prunus dulcis	1	0.10	0.01	0.05	<0.001	£45
Abies koreana	1	0.10	0.01	0.04	<0.001	£45
Thuja plicata	1	<0.10	<0.01	0.02	<0.001	£45
Ulmus minor	1	0.10	0.01	0.06	<0.001	£22
Total	213,778	52,028	1,550	60,423	35.70	£141,878,963

Appendix IV. Notes on Methodology

Data Formatting

Tables 5 to 9 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 Addition	Details	Number of records added
Count column, lists duplicate trees	These are trees which have duplicate details in each column.	172,832
	NUMBER OF RECORDS IMPORTED (Tree Groups)	**612**
	NUMBER OF RECORDS IMPORTED (Individual Trees)	**40,946**

Table 5: Inventory records added for use in Eco

Reason for Removal	Details	Number of records removed
No Species	There is no data in this field (a minimum requirement for iTree)	9,464
No DBH	There is no data in this field (a minimum requirement for iTree)	3,283
Condition = “Dead” / “Felled”	The tree has been classified as “dead” or “Stump”	354
	NUMBER OF RECORDS REMOVED	**13,101**

Table 6: Inventory records edited for use in Eco

Condition Text	iTree Equivalent
Good Condition	92%
Satisfactory Condition	82%
Fair Condition	72%
Poor Condition	62%

Table 7: Tree condition equivalents for use in Eco

Height (Supplied) (m)	DBH (Averaged) (cm)
0-3	7
4-6	14
7-9	21
10-14	28
15-19	35
20-24	42
25-29	49

Table 8: Height regression for missing dbh values

Individual Trees within the supplied dataset were reformatted for entry into Eco. Records with no species or dbh were deleted but if the record contained a height then the height regression table was used to provide an average dbh for that record (10,077 records).

Tree groups were assigned a representative species within the species mix for the group. If the dbh was missing and a height was provided then the height regression table was used to provide an average dbh for that record (182 records). When the single representative species were processed, results were duplicated by the stem count provided in the supplied dataset.

i-Tree

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

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

To calculate current carbon storage, biomass for each tree was calculated using equations from the literature and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations[15]. 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[16].

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[17]. 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[18] [19] that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere[20].Annual avoided surface runoff is calculated based on rainfall interception by vegetation, specifically the difference between annual runoff with and without vegetation. Although tree leaves, branches and bark may intercept precipitation and thus mitigate surface runoff, only the precipitation intercepted by leaves is accounted for in this analysis. The value of avoided runoff is based on estimated or user-defined local values. As the local values include the cost of treating the water as part of a combined sewage system the lower, national average externality value for the United States is utilised and converted to local currency with user-defined exchange rates.

Replacement Costs were based on valuation procedures of the Council of Tree and Landscape Appraisers, which uses tree species, diameter, condition and location information[21] [22].

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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15 Nowak 1994

16 Nowak, David J., Hoehn, R., and Crane, D. 2007.

17 Baldocchi 1987, 1988

18 Bidwell and Fraser 1972

19 Lovett 1994

20 Zinke 1967

21 Hollis, 2007

22 Rogers et al (2012)

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